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AN ARCHAEO-METALLURGICAL STUDY OF THE EARLY AND MIDDLE BRONZE AGE IN LURISTAN, IRAN

BY

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Abstract: Copper-base artefacts from Bronze Age Luristan have been analysed for their chemical composition and the isotopic composition of their lead. We find no significant systematic differences between a group of objects recovered in the Pusht-i Kuh region in the course of controlled excavations during the Belgian Archaeological Mission in Iran (BAMI) and a second group of artefacts from the Louvre Museum which were acquired on the art market. According to these material features the objects from the art market are made of genuine "Luristan" metal which does not exclude the possibility that the artefacts are recent forgeries made of "old" metal. The data suggest a large fraction of the artefacts, copper *and* bronze, to derive from copper ores as they are available in the eastern part of the central Zagros Mountains from where also tin ores have been reported. Bronzes with high ^{206}Pb-normalized abundance ratios, conspicuous in contemporary Mesopotamia, are missing in Luristan. We have no satisfactory explanation to offer why the manifold cultural and material connections between Mesopotamia and Luristan should have excluded the trade in bronzes with such exceptional lead isotopy.

Keywords: Iran, Luristan, Bronze Age, metallurgy, provenance study, lead isotopy.

Introduction

A metallurgical study of 3rd millennnium BCE copper-base artefacts from Luristan was initiated in 1986 by Françoise Tallon of the Louvre Museum as part of a wider research project on early Iranian metallurgy. The study focused on the collection of "Luristan" artefacts in the Louvre Museum with the goal to compare their metallurgical characteristics with those from other metallurgical centres in Iran. As the "Luristan" collection of the Louvre Museum did not come from controlled excavations but was acquired from various sources on the art market, there always remained, and still remains, some doubt about the specific origin and date of these objects. In

view of this, a selection of well-documented, excavated metal artefacts from the Belgian excavations in the Pusht-i Kuh region of Luristan was added to the study. Samples from the metal objects, which are now kept in the Royal Museums of Art and History, Brussels, were taken at Ghent University on 17 March 1987 by Françoise Tallon (Musée du Louvre) and Dr. Loïc-Pierre Hurtel (Laboratoire des Musées de France). These Pusht-i Kuh artefacts constitute a control group and, at the same time, provide the possibility to establish whether this sub-region had specific metallurgical characteristics. The Belgian excavations also provided the general chronological framework of the Early Bronze Age in Luristan.

Pusht-i Kuh, Luristan, research and chronology

The Belgian Archaeological Mission in Iran (BAMI) worked from 1965 until 1979 in the Pusht-i Kuh region of Luristan (now Ilam province, fig. 1). These expeditions, on the initiative of Ghent University and the Royal Museums of Art and History, Brussels, directed by Louis Vanden Berghe, targeted ancient graveyards. Chalcolithic, Bronze Age and Iron Age cemeteries were excavated and preliminary reports were regularly published in Iranica Antiqua, Archéologia and other periodicals (for a complete list see Haerinck & Overlaet 1996: 4-6). The publication of the final reports, the "Luristan Excavation Documents", started in 1996 and is still continuing (Haerinck & Overlaet 1996, 1998, 1999, 2004, 2006, 2008; Overlaet 2003).

A selection of the finds from the Belgian excavations is kept at the Royal Museums of Art and History, Brussels, and is available for advanced studies. Apart from the present study on the initiative of the Louvre Museum, other technological studies have been executed or are still in progress. In 1989 a project was started to have a large number of 3rd-1st millennium BCE copper/bronze objects analysed at the "Museum Applied Science Center for Archaeology" (MASCA), Philadelphia, USA. The first results have been published and more are to come in the near future (Fleming et al. 2005; Fleming et al. 2006).

In order to evaluate the present technological data in their proper geographical, cultural and historical settings, it is necessary to outline the general chronology of the Early Bronze Age in the Pusht-i Kuh as it appears from the BAMI excavations (Haerinck & Overlaet 2002, 2004, 2006: 66).

The name "Pusht-i Kuh" or "over the mountain" refers to the Kabir Kuh, the last major mountain range before the Mesopotamian lowland as seen from

the Iranian plateau (fig. 1). The region is characterised by intra-mountainous small plains or valleys and a rugged countryside. Larger plains are extending towards Khuzistan province in the South and the Pish-i Kuh ("before the mountain") in the North and East. Thus, the region sits between three major cultural areas of the ancient Near East, namely Central Western Iran, Mesopotamia and Elam. Moreover, at its north-western edge, it borders on the "Great Khorasan Road"which linked the Mesopotamian world to central Iran. It is thus plausible that the region can not be considered a closed entity and that simplified conclusions will never be possible. Influences, raw materials as well as finished products from various sources will always have found their way to Pusht-i Kuh. Indeed, all dating of the famed "Luristan bronzes" is based on stylistic similarities with non-Luristan artefacts which, of course, implies that close connections existed between Luristan and nearby cultural centers.

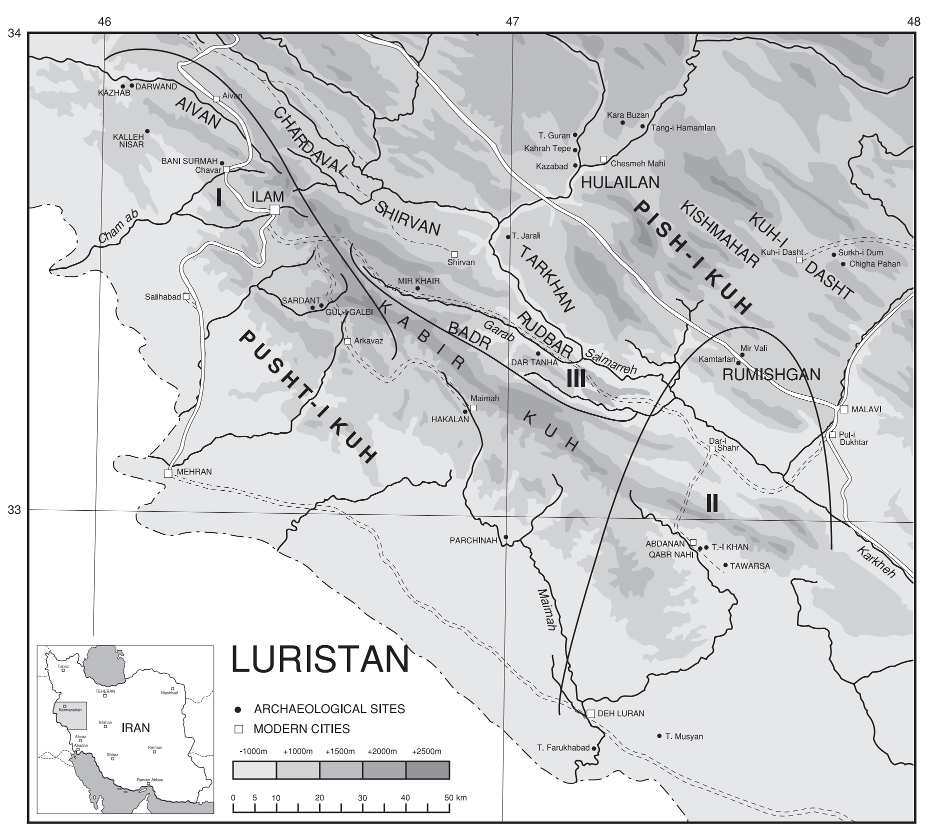


Fig. 1. Map of the Pusht-i Kuh with its three cultural zones during Phase II-III.

The archaeological evidence at hand allows a division of the Pusht-i Kuh into three regions for at least part of the third millennium, based on the tomb constructions and on the influence of neighbouring regions mainly recognisable in the pottery.

Before discussing the archaeo-metallurgical data, it is useful to outline the general chronology of the area. The third millennium BCE in Pusht-i Kuh is divided into three stages, an "Early" (Phase I), "Middle" (Phases II and III) and "Late" (Phase IV) Early Bronze Age.

Phase I, the earliest stage of the Early Bronze Age (late 4th/early 3rd mill. BCE = Djemdet Nasr and early Early Dynastic I in Mesopotamia) is characterised by small, mainly individual tombs. This phase is present at Mir Khair and at Kalleh Nisar, area AI. Metal is still rare in this phase and it is confined to simple items such as awls, flat axes, tanged knives, coiled bracelets and coiled finger rings. None of the objects analysed in the present study belong with certainty to this phase.

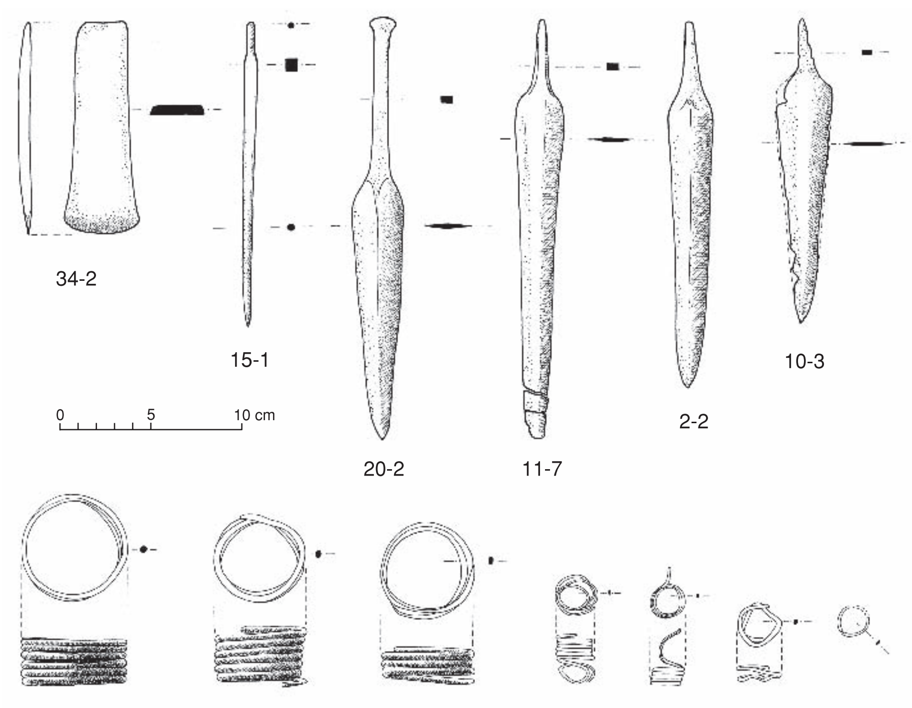


Fig. 2. Survey of metal artefacts from the Phase I graveyard at Mir Khair.

Phases II and III of the Early Bronze Age cover a large part of the 3rd millennium BCE (ED I to somewhere in the Akkadian period in Mesopotamia). Phase II is characterised by the construction of large communal corridor-shaped tombs (Pl. 1). Based on the evidence at hand it seems as if the construction of such tombs is limited to Early Dynastic I and II in terms of Mesopotamian chronology. There is at present no evidence for the construction of tombs during Phase III (Early Dynastic III and beginning of the Akkadian period in Mesopotamia). Rather, during Phase III the large communal tombs from Phase II continued to be used. Actually, some of these tombs were also occasionally re-used much later, some even as late as during the Isin-Larsa and Old Babylonian periods.

Since the tombs were used by many generations and individuals during which time objects were broken, displaced, removed and discarded, it is extremely difficult to attribute secure dates to single objects (see table 4). Often, only a broad and somewhat blurred picture emerges, based mainly on parallels with sites in other regions where more precise dates are available. Even so, simple objects, such as rings, can not be precisely dated, particularly when found in large communal tombs. This leaves the excavators in the frustrating and extremely unsatisfactory situation that objects acquired on the antiquities market, more often of unknown provenance and dubious origin, are generally "dated" more precisely than is possible for genuine artefacts procured with considerable efforts.

Several objects can roughly be attributed to the Early Dynastic III/Akkadian period, based on comparisons with finds from Mesopotamia or SW-Iran. One should be aware, however, that this comparative dating may easily distort our understanding of early metalwork. One has to realise that much more excavated material is available from these periods than from ED I/II. This may be partly due to chance, but probably also reflects a change in burial customs. It seems more metal artefacts were placed in tombs in the later part of the Early Dynastic period. Metal may simply have become more available or less costly, resulting in more metal artefacts being removed from circulation through deposition in tombs. As the known variety of ED I/II is consequently limited and incomplete, there is a general tendency to compare metal items to better documented Early Dynastic III/Akkadian artefacts. Most likely, several types commonly attributed to these periods, were already produced at an earlier date.

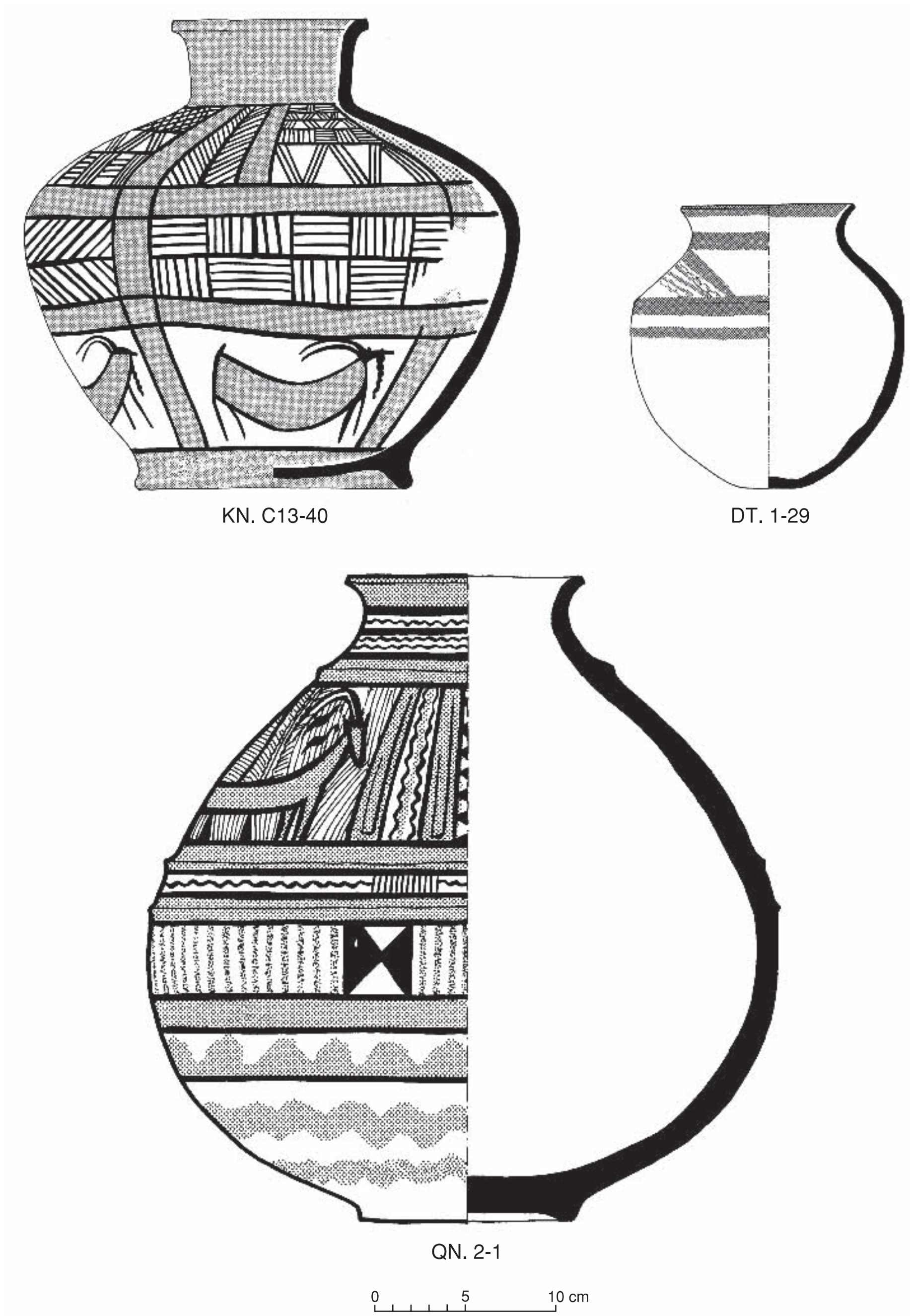


Fig. 3. Characteristic painted pottery of zone I (Kalleh Nisar, top left), zone II (Qabr Nahi, bottom) and zone III (Dar Tanha, top right).

Regionally, three different zones can be distinguished during Phases II and III, mainly by their painted pottery (figs. 1 and 3). The ***Mesopotamia-related "zone I"*** has by far the largest tombs in Pusht-i Kuh. They are up to 16 m long, are well built with large boulders and are covered with large flat stones (Pl. 1). A strong Mesopotamian influence in this part of the Pusht-i Kuh is obvious from its pottery. Among the plain pottery are imports and imitations of Mesopotamian types. Polychrome vessels with animals on the lower part are inspired by the Mesopotamian scarlet ware of the Hamrin and Diyala. Zone I tombs are known from Bani Surmah, Kalleh Nisar (area C) and Mehr War Kabud. Objects from all three sites are included in the present study.

The ***Deh Luran-related "zone II"*** in southern Pusht-i Kuh is characterised by 6 to 10 m long tombs with flat roofs. The monochrome ware shows simple geometric decorations. Shapes and decorations are particularly related to finds from Susa, Godin III:6 and Mir Vali, in Rumishgan. On the polychrome pottery metopes on the shoulder are characteristic, which frame trees or goats with elongated bodies and birds on their back. This polychrome style has particular parallels in the Deh Luran and the Rumishgan valley and thus seems to be confined to the southern part of Luristan. Such tombs were excavated at Pusht-i Qaleh-i Abdanan, Qabr Nahi, Takht-i Khan and Tawarsa. Metal is very rare in the tombs. No metal artefacts of this zone II were investigated in the present study.

The tombs in the ***Pish-i Kuh-related "zone III"***, to the North of the Kabir Kuh, are similar to those in the central part of the Pish-i Kuh. They are also corridor-shaped and measure between 6 and 8 m in length, but they have a gabled roof (Pl. 7). Monochrome painted jars are related to the central Pish-i Kuh, particularly to Godin III:6 pottery. The rare presence of zone I-related polychrome pottery in association with zone III monochrome ware testifies to existing interzonal contacts. Five metal objects from zone III tombs at Dar Tanha were included in the study.

Phase IV, the latest stage of the Early Bronze Age, documents the last few centuries of the 3rd millennium and the early 2nd millennium BCE. In terms of Mesopotamian chronology this covers the later part of the Akkadian period, the Guti and the Ur III period, and possibly part of the Isin-Larsa period. There is a clear difference in tombs and burial customs in the Pusht-i Kuh in comparison with the preceding Phases II-III. The so-called "Gutian" tombs of the Late Phase are small tombs of 1.20 to 1.70 m length with

only three sidewalls constructed from stones (Pl. 2). Among the burial goods are monochrome painted jars inspired by Pish-i Kuh types but with a simpler decoration (triangles and groups of vertical lines). Some plain vessels are Mesopotamian imports. Metal objects are quite common among the burial goods. Characteristic are shafthole axes of folded sheet metal. Phase IV tombs, of which metal objects are incorporated in the present study, were discovered at Kalleh Nisar AII, Darvand A, Gululal-i Galbi and Sardant. These sites are all located in "zone I" and since no material from the other zones is available, it is at present not possible to ascertain whether the cultural variation within the Pusht-i Kuh attested in Phases II and III, continues to exist in Phase IV.

The Louvre collection of Luristan "Bronzes"

The artefacts from the Louvre incorporated in this study come from the antiquities market (see Table 2, column 3). With but a few exceptions they were acquired before scientific excavations had been carried out in Luristan, but at a time when the metal production of the region was already well known owing to numerous objects of outstanding technical and aesthetic qualities from clandestine excavations which, since 1928, had attracted the attention of collectors and museum curators. Most of the pieces were purchased before 1935. Among those, some come from the collection of André Godard, the Director of Antiquities in Tehran who visited the region neighbouring Harsin, the town where the first "Luristan bronzes" appeared on the market. Godard bought some of them and published them as early as 1931, together with details of his exploration of the region (Godard 1931). The six items from the collection of D. David-Weill were acquired in 1931 and 1932; they comprise a Bactrian axe (Louvre-39, Pl. 18) which was included for comparison; the five pieces from the Citroën collection were no doubt purchased during the "Croisière jaune" expedition in 1931-1932; and still others were obtained at Nehavand between 1930 and 1932 in the course of the Contenau-Ghirshman missions (see Contenau & Ghirshman 1935: v-vi). Also in 1931 the rein ring (Louvre-12, Pl. 13) and two daggers (Louvre-3 and 14, Pl. 12, 14) and an axe (Louvre-46, Pl. 19) were bought by the Musée du Louvre. Among those acquired later, eighteen are from the collection of the French diplomat J.-C. Coiffard who purchased them while posted in Tehran (acquired by the Louvre in 1958; see Amiet 1963); and two are owing to the generosity of the great Tehran collector and connoisseur Mohsène Foroughi (Louvre-47 & 48, Pl. 19).

The Louvre objects are strikingly different from the corpus of rather mundane artefacts actually *excavated* in Luristan by the BAMI, since they were acquired because of their aesthetic appeal and superior technical quality, in some cases for their zoomorphic decoration. They are generally considered genuine owing to the fact that most of them were purchased at an early date and/or in Iran by expert collectors. At the time they were acquired, all copper-base objects with such decoration were labelled "Luristan bronzes" -indeed they served to define "Luristan bronzes"-, but we know by now that some of them may come from other regions, particularly from Bactria or from Elam. And we also know by now that many of the objects are not bronzes in the scientific sense in that they contain but traces of tin, not the canonical tin content of 1 % or more which is generally considered to separate bronzes from non-bronzes.

Chronologically, the objects can be divided into three periods. The earliest objects date from the middle of the Early Bronze Age, ca 2600-2300 BCE (Louvre-1 to 15, Pls. 12-14) which corresponds to Phase III of the Belgian excavations and to the Early Dynastic III/Early Akkadian period in Mesopotamia; objects from the late Early Bronze Age, ca 2300-2000 BCE (Louvre-16 to 33, Pls. 14-17), correspond to Phase IV of the BAMI excavations and Late Akkadian, Guti, and Ur III periods in Mesopotamia. Finally a few of the artefacts belong to the first centuries of the 2nd millennium BCE (Louvre-34 to 43, Pl. 17, 18).

From the first period some of the objects are stylistically related to Mesopotamian artefacts: a chariot rein ring decorated with human figures (Louvre-12, Pl. 13) recalls similar ones from Ur and Kish; a battle axe with sinuous profile (Louvre-6, Pl. 12) is identical to those depicted on monuments at Ur, Kish, and Mari, and is also similar to specimens found at Bani Surmah, area A, and at Susa. A footed goblet (Louvre-10, Pl. 13), finally, is related to one made of gold and found in the tomb of Pu-abi at Ur. Others are of Iranian types: tubular mace heads similar to those from Susa or more richly decorated (Louvre-1 and 7 to 9, Pls. 12, 13); daggers with riveted metal handles, decorated in relief, and wide blades with vertical lines (Louvre-3, 4, 14 and 15, Pls. 12, 14), resembling more precious models from the Royal Tombs at Ur, but nevertheless typical of Luristan where a complete example was excavated at Takht-i Khan, in central Pusht-i Kuh (Vanden Berghe 1973: 29); and blades from Mehr War Kabud and Bani Surmah, area A. Of Iranian type are also one globular spouted vessel (Louvre-5, Pl. 12), only known from Iran, as well as three spouted vessels decorated with

scrolls or braids (Louvre-2, 11 and 13, Pls. 12, 13) of a type known from different parts of Iran and Bactria, but also attested in Mesopotamia although there they occur less frequently and without decoration.

The second chronological period (Louvre-16 to 33, Pls. 14 to 17) is essentially represented by axes, most of them of Iranian type. There are axes or pick axes characterised by a flange butt with a horizontal ridge, identical with examples from Kalleh Nisar A II (Vanden Berghe 1970: 72), Surkh Dum-i-Luri and Susa (Tallon 1987), which are also known from Til Barsip in Syria. Others have long shaft holes, decorated with spikes, or show a curved protuberance on the butt. Of Mesopotamian type, but also found in Iran, are axes with a conical projection at the butt, sometimes referred to as Naram-Sin axes because one of them is depicted on the stele, now in the Louvre, of Naram-Sin, king of Akkad during the middle of the 23rd century BCE. Finally, there are a Bactrian-type hammer with lock-like curls on the butt and birds' heads at the top (Louvre-29, Pl. 16), similar to one found at Susa inscribed with the name of Shulgi, second king of the 3rd dynasty of Ur, and a tubular mace head with a ribbed bulge (Louvre-32, Pl. 16) which is of a type well represented among the collections of "Luristan bronzes" with one of them being inscribed with Naram-Sin's name (Dossin 1962: 158-159, pl. XXV).

The artefacts of the third period (Louvre-34 to 43, Pls. 17, 18) are again mostly of Iranian type: Atta-hushu and related types of axes; axes with zoomorphic decoration, one with the head of a lion "spitting the blade", as it appears also at Susa although in this case the lion's head is missing. On another shafthole axe the blade is cast as the body of an upside-down placed lion, head and front legs forming the shaft hole (Louvre-37, Pl. 17). And finally there is a bronze loop held by human hands (Louvre-43, Pl. 18), possibly a belt buckle, identical with examples excavated at Susa.

Archaeo-metallurgy

Chemical composition

Fifty-eight of the excavated artefacts (Table 1, Pls. 3 to 11) and 48 of the purchased objects from the Louvre collections (Table 2, Pls. 12 to 19) were investigated for their chemical composition. Among the artefacts from the Louvre there is a preponderance of axes and other heavy implements. This dominance of heavy objects presumably reflects the art market where

massive artefacts are more common than are unobtrusive items like awls, needles, pins and finger rings.

Analyses for antimony, arsenic, bismuth, cobalt, gold, iron, lead, nickel, silver, tin, and zinc were performed in the Laboratoire des Musées de France, Paris by optical atomic emission spectroscopy (AES) (Tables 1 & 2). Aliquants of 30 of the Louvre samples were also subjected to neutron activation analysis (NAA) to determine their contents of antimony, arsenic, cobalt, nickel, silver, and tin. The agreement between the results obtained by the two analytical techniques is remarkably good (Pernicka, personal communication), in particular when taking into account the wide range of concentrations encountered. Between the samples the absolute concentration of arsenic varies about hundredfold, that of silver by more than a factor of 300, and the contents of antimony, nickel and cobalt vary by more than a factor of thousand. For the individual elements the mean ratios of AES-concentrations to NAA-concentrations are 0.91 for antimony, 1.36 for arsenic, 1.14 for cobalt, 0.85 for nickel, 1.01 for silver and, in the bronzes, 1.01 for tin. For the sake of consistency we use the AES-data from the Louvre throughout. Moreover, we restrict ourselves to mentioning some summary features, not all of which have been pointed out before.

A major difference between the bronzes from western Pusht-i Kuh and those acquired on the art market is their tin content.[1] Among the excavated objects the spread in tin content is only half as wide, between 2 % and 8 % tin, as it is in the purchased ones where the range is between 2 % and 16 % tin (fig. 4). Moreover, in the BAMI artefacts there is a pronounced peak in the distribution curve of tin contents at around 3 %, in the samples from the Louvre an equally pronounced one at around 10 % tin. It would appear that,

[1] We follow the conventional definition of bronze as copper containing more than 1 percent of tin. As suggested by the hiatus at around 1 % tin in the bi-modal distribution of the tin contents (fig. 8, lower panel) the same limit appears to be reasonable for the present artefacts, also. Moreover, such a distribution indicates the bronze in Luristan to be a deliberate alloy which did not come about by accidentally co-smelting copper ores "contaminated" to a variable degree with ores of tin. _ Arsenical copper, with a few percent of arsenic, qualifies also as a two-component alloy. For arsenic, however, one observes invariably a single-mode distribution of its concentration around a most-frequent value (fig. 5) which varies from region to region (see, e.g., Berthoud et al. 1982). This makes the definition of any arsenic concentration to distinguish between As-rich copper and As-poor copper somewhat arbitrary; in the present instance we have chosen as separation line a concentration of 2 %.

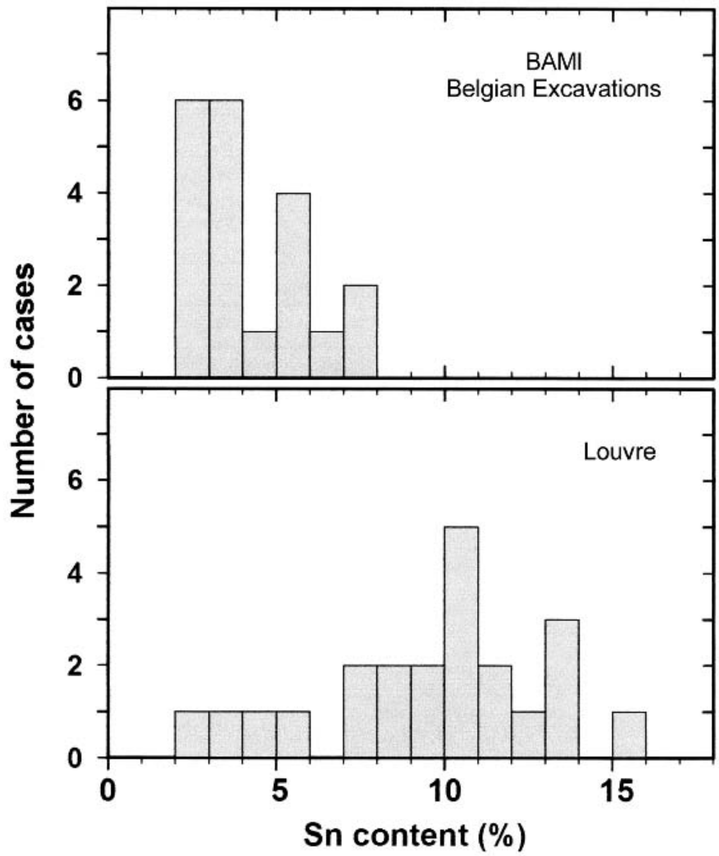


Fig. 4. The distribution of tin content among bronze objects excavated in Western Luristan (Pusht-i Kuh) is markedly different from that in artefacts acquired on the art market.

assuming a local production of the bronze, in western Luristan there was a better control over the tin content and, moreover, that tin was used more sparingly. Possibly tin was also less readily available in Luristan.

The mean (and median) arsenic contents of the non-bronzes are higher than those of the bronzes by a factor of 2-3 (fig. 5). We interpret this to mean that, towards the end of the 3rd millennium BCE, metallurgists in Luristan, or those who supplied the metal to Luristan, were well aware that the beneficial features resulting from alloying copper with a few percent of tin are, to a large extent, the same as those of copper containing a few percent of arsenic. The craftsmen must have realised that the addition of tin to

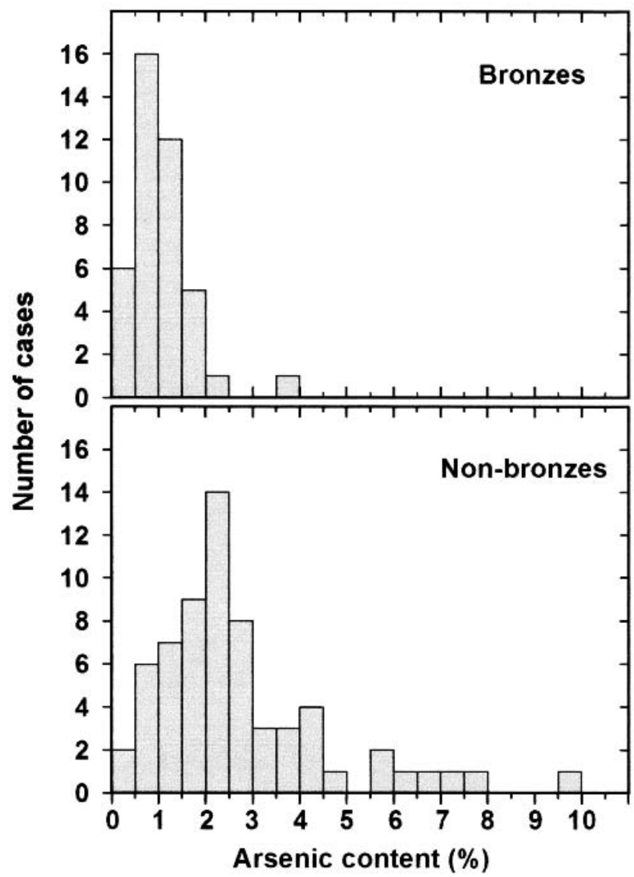


Fig. 5. The arsenic contents of bronzes and non-bronzes from Luristan both show a modal distribution, but the distribution curve for the bronzes is shifted to lower concentrations. Average concentrations are 1.06 % of arsenic for the bronzes and 2.73 % for the non-bronzes. From a rational point of view this is perfectly reasonable since the addition of (valuable) tin to copper containing more than a few percent of arsenic will not significantly improve on the material properties of the metal.

such arsenical copper would not significantly improve on the material qualities; rather, it would be a waste of a valuable commodity. By implication, the metallurgists must then also have been able to distinguish arsenic-rich copper with, say, more than 2 % of arsenic from such with less than 2 %. It is not clear at present whether this was done based on some material feature of the smelted metal or whether the ores utilized for smelting were already chosen accordingly.

In addition to (tin)bronze and arsenical copper there are a few lead-rich alloys[2]. Most of them are binary alloys, but there are also lead-rich *bronze* objects with around 2 % lead. Two of them qualify as intentional lead alloys if we choose, somewhat arbitrarily, a concentration of 2 % to separate intentional alloys from accidentally lead-rich metal where the lead originated with the copper ores utilized. Nine objects have lead contents between 8 % and 16 % which is almost certainly due to the deliberate addition of lead. Because of their higher fluidity and reduced surface tension the castability of such lead-rich alloys is far superior to pure copper, and also superior to bronze, which facilitates the casting of intricate objects or such with elaborate surface ornamentation. Thus, it makes sense, metallurgically speaking, that the rein ring (Louvre-12, Pl. 13) and also the two richly decorated ED III mace heads Louvre-1 and Louvre-7 (Pls. 12, 13) should be made of such alloys. It is surprising, however, to find also some axes and picks (Louvre-21, 25, 30, 31) to be made of copper with ca 10 % lead because the properties one expects of implements to be used for work are rather detrimentally affected by such high lead contents. But then style and the absence of signs of wear anyhow suggest these implements to have been ceremonial objects never meant for daily use. This is true for some of the axes and picks from the Louvre collections (Pls. 14 to 18), but it is obviously also the case for an axe from Kalleh Nisar (BAMI-43, Pls. 9, 10) which is made from folded copper sheet metal which makes it rather useless as a tool, be it for cutting or for splitting, or as a weapon. It should be noted that such lead-rich alloys are found among the excavated objects as well as among the bought objects, emphasizing that lead-rich alloys do not automatically indicate forgeries.

The concentrations of trace elements antimony (Sb), bismuth (Bi), cobalt (Co), gold (Au), nickel (Ni) and silver (Ag) are very much the same in the artefacts from the two subsets of objects (Tables 1 & 2, fig. 6). There also seem to be no significant differences between bronzes and non-bronzes in the contents of these trace elements; for Ag, Co, Ni and Sb this is illustrated in fig. 6. Together with the arsenic evidence

[2] For lead contents above the solubility limit of lead in copper of ca. 1 % measured concentrations are notoriously irreproducible. This is true in particular if only small samples are analysed where the sample size is commensurate with the size of the lead blobs segregated from the copper.

Table 1: Chemical composition and trace element contents of copper-base artefacts from Luristan excavated by the BAMI. Analyses by optical emission spectroscopy were performed by Drs. L. Hurtel and M. Menu at the Laboratoire de Recherche des Musées de France of the Louvre, Paris. Samples marked in column 1 with an asterisk (*) have also been analysed for the isotopic composition of their lead (see table 3).

(1) Initials of site (BS = Bani Surmah, DA = Darvand, DT = Dar Tanha, GLG = Gululal-i Galbi, KN = Kalleh Nisar, MWK = Mehr War Kabud, SD = Sardant), followed by "Area" (if applicable: A, B, C or AII), tomb number and number of the object in the tomb.

No.	Excavation No. (1)	Lab. No.	Pb [%]	Sn [%]	As [%]	Sb [µg/g]	Fe [µg/g]	Ag [µg/g]	Ni [µg/g]	Bi [µg/g]	Co [µg/g]	Au [µg/g]	Zn [µg/g]	Type of object	Pl.	Final excavation reports (Luristan Exc. Documents)
BAMI-1 *	BS.A6-32	17850	2.130	3.150	0.292	140	2820	280	3100	440	900	1	80	bracelet	3	LED VI: 46, fig. 22, pl. 23
BAMI-2	BS.A1-5	17851	0.172	0.200	0.602	760	5750	960	2650	90	470	2	50	pin	3	LED VI: 43-46, fig. 21, pl. 9
BAMI-3	BS.A13-6	17852	0.089	0.004	1.000	830	2600	1130	530	30	20	1	10	pin	3	LED VI: 43-46, fig. 21, pl. 30
BAMI-4	BS.A3-4	17853	0.527	5.200	0.493	130	1820	580	670	30	120	14	10000	pin	3	LED VI: 43-46, fig. 21, pl. 14
BAMI-5	BS.A14-41	17854	0.322	2.020	1.550	310	2280	730	8030	150	140	21	60	awl	3	LED VI: 40, fig. 18, pl. 41, 43
BAMI-6	BS.A2-20	17855	0.060	0.125	0.985	360	3050	300	2000	30	80	1	20	saw	3, 4	LED VI: 37-39, fig. 17, pl. 11-12
BAMI-7	BS.A3-3	17856	0.195	0.033	1.770	310	10500	1070	1500	30	60	14	20	dagger	3	LED VI: 30-32, pl. 14
			0.206	0.065	2.530	800	13500	1250	4230	30	120	10	20			
BAMI-8	BS.A2-15	17857	0.284	0.008	1.700	8000	7150	660	4500	30	500	7	120	dagger	3, 4	LED VI: 30-32, pl. 11, 13
			0.110	0.004	0.270	40	43200	520	760	30	500	4	80			
BAMI-9	BS.A14-37	17858	0.108	0.045	2.200	2300	13200	1230	4500	30	60	12	60	dagger	3	LED VI: 30-33, fig. 14, pl. 41
			0.160	0.323	2.030	850	9250	1620	7580	30	140	12	30			
BAMI-10	BS.A14-54	17859	0.039	0.002	2.520	220	70	1400	690	160	5	1	420	vessel	3, 4	LED VI: 41-42, fig. 20, pl. 41, 43
BAMI-11 *	BS.A2-2	17860	0.150	0.025	1.820	600	1270	1180	2500	30	20	28	10	axe	3, 4	LED VI: 35-37, fig. 16, pl. 11, 13
BAMI-12	BS.A13-4	17861	0.388	0.048	2.700	750	6830	1430	7120	40	180	18	30	axe	3	LED VI: 35-37, fig. 16, pl. 30
BAMI-13 *	BS.A2-9	17862	7.850	0.003	0.272	30	200	100	3530	30	60	5	60	axe	3, 4	LED VI: 35-37, fig. 16, pl. 11, 13
BAMI-14	BS.A2-3	17863	0.112	0.002	1.630	620	9900	620	200	120	14	6	50	axe	5	LED VI: 35-37, pl. 11
BAMI-15 *	BS.A2-7	17864	2.000	0.005	2.500	300	3040	560	2170	30	7	8	10	axe	5	LED VI: 35-37, pl. 11
BAMI-16	BS.A2-11	17865	0.089	0.195	2.000	670	11800	1150	2580	30	210	7	10	chisel	5	LED VI: 32-35, fig. 15, pl. 11
BAMI-17 *	BS.B12-4	17866	0.735	3.300	1.000	600	6000	250	3280	110	2230	16	50	pin	5, 6	LED VI: 43-46, fig. 21, pl. 64

No.	Excavation No. (1)	Lab. No.	Pb [%]	Sn [%]	As [%]	Sb [µg/g]	Fe [µg/g]	Ag [µg/g]	Ni [µg/g]	Bi [µg/g]	Co [µg/g]	Au [µg/g]	Zn [µg/g]	Type of object	Pl.	Final excavation reports (Luristan Exc. Documents)
BAMI-18	BS.B11-2	17867	0.064	3.000	1.300	790	1730	250	3820	80	650	7	10	pin	5, 6	LED VI: 43-46, fig. 21, pl. 63
BAMI-19	BS.B14-1	17868	0.246	0.040	2.100	740	10500	350	960	30	46	2	50	axe	5, 6	LED VI: 35-37, fig. 16, pl. 65
BAMI-20 *	KN.AI.1-4	17869	0.363	3.200	0.987	950	5730	770	1460	30	200	10	30	finger ring	5	LED VII: fig. 21, pl. 3
BAMI-21	KN.AI.3-1	17870	0.093	2.730	0.570	80	4100	170	4970	30	340	6	10	pin	5, 6	LED VII: fig. 19, pl. 3, 67
BAMI-22 *	KN.AI.3-2	17871	0.170	2.770	0.934	140	8950	260	5770	90	570	10	40	pin	5, 6	LED VII: fig. 19, pl. 3, 67
BAMI-23 *	KN.AI.4-5	17872	0.245	2.900	0.693	370	2220	370	4340	170	440	13	80	bracelet	5	LED VII: fig. 20, pl. 3
BAMI-24	KN.AI.12-8	17873	0.039	0.066	2.250	3170	15200	430	11000	140	190	3	10	pin	5,6	LED VII: fig. 19, pl. 8, 67
BAMI-25 *	KN.AI.2-4	17874	0.401	2.330	0.740	330	7280	800	630	120	120	7	60	bracelet	5	LED VII: fig. 20, pl. 3
BAMI-26	KN.AI.2-8	17875	0.033	5.800	0.507	80	1950	450	330	70	140	12	50	vessel	5, 6	LED VII: fig. 17, pl. 3, 66, XXV
BAMI-27 *	KN.C3-30	17876	0.402	3.650	0.976	1260	1380	770	2660	90	340	12	30	dagger	5, 6	LED VII: fig. 14, pl. 18, 63
BAMI-28 *	KN.C13-79	17877	0.142	0.796	1.800	270	700	1100	1560	30	80	5	40	finger ring	5	LED VII: pl. 31
BAMI-29	KN.C3-33	17878	0.043	5.230	0.240	70	1500	620	270	70	30	13	10	pin	5	LED VII: fig. 19, pl. 18, 67
BAMI-30 *	KN.C13-31	17879	0.072	0.153	0.211	190	300	240	500	30	80	7	50	pin	5	LED VII: fig. 19, pl. 30
BAMI-31 *	KN.C13-33	17880	0.294	7.350	0.505	360	1820	660	2460	30	120	27	10	pin	5	LED VII: fig. 19, pl. 30
BAMI-32 *	KN.C12-11	17881	0.105	3.950	0.765	260	1880	300	1920	30	240	19	270	spearhead	5, 6	LED VII: fig. 15, pl. 29, 64, XXIV
BAMI-33 *	DT.1-8	17882	0.130	0.013	3.330	730	4450	1850	4050	30	10	1	10	dagger	7, 8	LED IX
BAMI-34 *	DT.1-18	17883	0.016	0.002	0.635	150	7030	950	730	30	30	1	10	bracelet	7, 8	LED IX
BAMI-35	DT.1-14	17884	0.028	0.034	2.830	1780	4000	1920	480	30	10	3	10	awl	7, 8	LED IX
BAMI-36 *	DT.1-17	17885	9.250	0.010	2.550	1060	2600	1300	1780	40	30	1	80	belt buckle	7, 8	LED IX
BAMI-37 *	DT.1-12	17886	0.121	0.004	2.850	1530	4580	1550	2220	250	50	1	20	dagger	7, 8	LED IX
BAMI-38 *	DT.1-2	17887	0.128	0.005	2.160	560	3300	1450	920	160	7	1	30	axe	7, 8	LED IX
BAMI-39 *	MWK.3-1	17888	0.288	4.300	1.650	1150	5200	1350	12000	180	310	13	160	dagger	9	LED VIII: pl. 23
			0.261	2.820	1.500	360	5850	1550	3250	90	170	9	30			
BAMI-40	MWK.3-4	17889	0.052	0.056	2.150	1210	6900	1020	7450	30	220	3	10	blade/chisel	9	LED VIII: pl. 23
BAMI-41 *	MWK.4-2	17890	0.028	0.157	2.400	1950	9440	700	550	30	15	6	10	dagger	9, 10	LED VIII: pl. 24

No.	Excavation No. (1)	Lab. No.	Pb [%]	Sn [%]	As [%]	Sb [µg/g]	Fe [µg/g]	Ag [µg/g]	Ni [µg/g]	Bi [µg/g]	Co [µg/g]	Au [µg/g]	Zn [µg/g]	Type of object	Pl.	Final excavation reports (Luristan Exc. Documents)
BAMI-42	KN.AII.13-4	17891	0.036	0.097	1.100	310	5400	180	2860	30	100	5	10	spearhead	9	LED VIII: pl. 51, 65
			0.958	0.007	0.428	30	170	1100	70	30	16	4	50			
			0.100	0.305	1.530	450	9540	300	3700	30	540	6	20			
BAMI-43 *	KN.AII.2-2	17892	1.000	0.009	0.895	250	3830	1420	3100	30	100	4	20	axe	9, 10	LED VIII: pl. 50, 66
BAMI-44	KN.AII.6-5	17893	0.245	0.016	2.170	680	1120	1450	2270	30	70	11	10	axe	9, 10	LED VIII: pl. 52, 66
BAMI-45 *	KN.AII.13-6	17894	0.886	0.010	1.600	14600	8650	190	13200	170	390	1	10	axe	9	LED VIII: pl. 51, 67
BAMI-46	KN.AII.42-11	17895	0.062	0.100	2.300	340	11000	860	2600	30	110	5	110	pendant	9, 10	LED VIII: pl. 56, 70
			0.056	0.095	2.340	300	10200	800	2470	30	100	4	10			
BAMI-47 *	KN.AII.14-8	17896	0.105	0.026	2.060	300	13300	1230	2570	210	150	31	10	pendant	9, 10	LED VIII: pl. 51, 70
			0.116	0.027	2.450	360	12500	1140	3050	100	160	39	10			
BAMI-48	KN.AII.34-11	17897	0.075	0.047	1.380	340	3280	1220	2260	30	240	3	10	pin	9	LED VIII: pl. 54, 68
BAMI-49	KN.AII.44-2	17898	0.128	0.043	0.574	140	1100	960	2950	30	180	1	10	bracelet	9	LED VIII: pl. 56
BAMI-50	KN.AII.2-6	17899	0.080	0.036	1.450	200	10500	550	1900	30	640	5	10	vessel	9, 10	LED VIII: pl. 50, 68
BAMI-51	SD.1-9	17901	0.137	0.217	1.060	220	4200	3220	1820	30	180	1	10	dagger	11	LED VIII: pl. 76, 79
BAMI-52 *	SD.1-13	17902	0.665	0.009	1.640	430	1950	2000	2180	30	20	3	10	bracelet	11	LED VIII: pl. 76, 80
BAMI-53	SD.1-14	17903	0.188	0.009	1.760	450	9750	2300	2660	30	50	7	10	bracelet	11	LED VIII: pl. 76, 80
BAMI-54 *	SD.1-15	17904	0.859	0.008	1.620	380	2150	1920	2160	30	20	6	10	bracelet	11	LED VIII: pl. 76, 80
BAMI-55	GLG.1-10	17905	0.604	0.008	2.180	520	5420	2000	1420	50	7	2	10	blade	11	LED VIII: pl. 31-32
BAMI-56 *	GLG.1-16	17906	0.416	5.050	1.820	300	240	2920	1180	70	25	11	10	bracelet	11	LED VIII: pl. 31, 33
BAMI-57 *	GLG.1-14	17907	0.797	6.000	0.930	750	1950	600	1730	50	200	20	10	pin	11	LED VIII: pl. 31, 72, 75
BAMI-58 *	DA.2-5	17908	0.166	7.150	0.688	510	960	430	2650	50	60	22	10	bracelet (fragm.)	11	LED VIII: pl. 38

Table 2: Chemical composition and trace element contents of copper-base „Luristan“ artefacts from various Louvre collections. Samples marked in column 1 with an asterisk (*) have also been analysed for the isotopic composition

No	Inv. No Louvre	Provenance	Lab. No	Lab. No	Pb [%]	Sn [%]	As [%]	Sb [µg/g]	Fe [µg/g]
		Early Dynastic III							
Louvre-1 *	AO 20 436	Coll. Coiffard	14774	4031	15.860	0.030	1.23	470	240
Louvre-2	AO 20 452	Coll. Coiffard	14775	236	0.083	0.016	6.34	900	1050
Louvre-3 *	AO 14 054	Acquired 1931	14778	232 I	0.185	0.030	1.27	690	2310
				232 II	0.200	0.061	2.08	990	2730
Louvre-4	AO 20 880	Coll. Coiffard	14779	234	3.860	0.001	8.20	27700	1050
					0.032	0.001	6.23	120	1250
Louvre-5 *	AO 20 451	Coll. Coiffard	14780	3541	0.171	0.001	4.14	910	1570
Louvre-6 *	AO 24 013	Acquired 1970	14787	3542	0.043	0.043	2.18	4510	4720
Louvre-7 *	AO 13 906	Coll. Godard	14790		10.000	0.023	2.34	4840	180
Louvre-8 *	AO 20 435	Coll. Coiffard	14792		0.006	0.018	1.51	16600	490
Louvre-9 *	AO 24 792	Coll. David-Weill	14793	3552	0.919	0.001	4.24	42000	540
					0.885	0.003	4.28	48800	230
Louvre-10 *	AO 13 916	Coll. Godard	14794		0.692	0.042	2.67	800	1830
Louvre-11	AO 20 456	Coll. Coiffard	14796		1.100	0.021	4.63	360	3080
Louvre-12 *	AO 14 056	Acquired 1931	14798		12.420	0.051	9.79	640	4690
Louvre-13 *	AO 21 635	Acquired 1960’s		4028	< 0.300	0.060	5.70	2000	4400
Louvre-14 *	AO 16 603	Acquired 1931		4029 I	15.900	0.220	4.50	6700	32000
				4029 II	1.300	0.220	4.10	6000	28000
Louvre-15 *	AO 18 663	Citroën “Croisière jaune”		4030 I	1.000	0.080	4.10	5800	2900
				4030 II	1.000	< 0.060	3.70	5300	5200
		Akkadian/Ur III							
Louvre-16 *	AO 11 985	Acquired 1930, Nehavend area	14753	212	0.324	15.320	0.88	1120	1770
Louvre-17 *	AO 11 986	Acquired 1930, Nehavend area	14754	213	0.003	12.060	0.34	20	1200
Louvre-18 *	AO 13 883	Coll. Godard	14755	214	1.560	0.050	5.86	660	5090
Louvre-19 *	AO 13 884	Coll. Godard	14756	215	0.466	7.000	1.98	2580	2280
Louvre-20 *	AO 13 885	Coll. Godard	14757	228	0.223	2.650	1.35	780	410
Louvre-21 *	AO 18 670	Citroën “Croisière jaune”	14759	218	15.700	0.010	3.34	180	820

of their lead. Chemical analyses by optical emission spectroscopy were performed by Drs. L. Hurtel and M. Menu at the Laboratoire de Recherche des Musées de France, Paris.

Ag [µg/g]	Ni [µg/g]	Bi [µg/g]	Co [µg/g]	Au [µg/g]	Zn [µg/g]	Type of object	Dimensions H. / L.	Pl.	Bibliography
960	1490	70	1	12	1	mace head	15.6 / –	12	–
1810	69	70	< 1	2	50	vessel	9.8 / 12.6	12	Calmeyer 1969:14-D.
324	1980	60	57	8	1	dagger, haft	25 / –	12	–
677	2860	60	50	15	1	, blade			
938	19800	60	82	1	1	dagger	26 / –	12	Calmeyer 1969: 18.
112	850	60	114	1	1				
1330	41	128	1	7	1	vessel	10.2 / 23.8	12	–
700	94	210	4	7	1	axe	8.8 / 15.6	12	–
1810	325	500	20	4	1	mace head	15.0 / –	13	Godard 1931: pl. XIX:58.
31	14900	111	1230	18	1	mace head	23.1 / –	13	–
6050	265	47	1	1	1	mace head	13.4 / –	13	Pope 1938: pl. E-F; Calmeyer 1969: 20, fig. 20; Amiet 1976: 8, nr. 6.
6040	158	212	1	1	1				
4750	1060	103	22	10	1	vessel	10.0 / 11.2	13	Godard 1931: pl. LXI-223; Calmeyer 1969: 12-13, Abb. 9.
2340	2500	219	132	44	5	vessel	11.4 / 21.0	13	Calmeyer 1969: 14-15, Abb. 12.
290	3460	211	444	2	3	rein ring	18.4 / 8.8	13	Dussaud 1932: 227-228, fig. 2-3; Pope 1938: pl. 26B; Calmeyer 1969: 8-9, Abb. 1; Orthmann 1975: pl. 37b; Amiet 1977: fig. 346; Braun-Holzinger 1984: nr. 112.
1100	< 2000	–	–	–	< 3000	vessel	13.0 / –	13	Calmeyer 1969:14, nr. 5D.
800	3900	–	–	–	< 3000	dagger, haft	25.0 / –	14	Calmeyer 1969:18, nr. 6M, Abb. 16.
400	6400	–	–	–	< 3000	, blade			
500	22000	–	–	–	< 3000	dagger, haft	28.2 / –	14	–
700	23000	–	–	–	< 3000	, blade			
39	342	600	75	2	24	axe	7.7 / 12.3	14	Dussaud 1930: 249, pl. XLII:2; Deshayes 1960: nr. 1359.
3440	380	752	70	1	1	axe	11.6 / 9.9	14	Dussaud 1930: 248, pl. XLII:1; Deshayes 1960: 167, nr. 1365.
790	680	820	16	1	1	axe	7.3 / 9.3	14	Godard 1931: pl. XV:46; Deshayes 1960: 158, nr. 1276.
1360	1350	635	106	4	1	axe	5.1 / 8.8	14	Godard 1931: pl. XV-45; Deshayes 1960: 158, nr. 1284.
772	4520	490	191	7	1	pick	7.5 / 16.5	15	Godard 1931: pl. XV-47; Deshayes 1960: nr. 1353.
136	90	1770	1	1	1	axe	8.2 / 12.2	15	Deshayes 1960: 166, nr. 1347, pl. XIX-4.

No	Inv. No Louvre	Provenance	Lab. No	Lab. No	Pb [%]	Sn [%]	As [%]	Sb [µg/g]	Fe [µg/g]
Louvre-22 *	AO 18 671	Citroën "Croisière jaune"	14760	219	0.295	13.700	1.31	190	510
Louvre-23 *	AO 20 408	Coll. Coiffard	14762	229	1.220	9.180	1.08	2750	1060
Louvre-24 *	AO 20 420	Coll. Coiffard	14764	222	0.656	13.070	0.70	290	2040
Louvre-25 *	AO 20 421	Coll. Coiffard	14765	223	13.410	0.194	0.67	120	11000
Louvre-26 *	AO 20 422	Coll. Coiffard	14766	224	0.930	10.530	0.77	240	1100
Louvre-27 *	AO 20 423	Coll. Coiffard	14767	225	1.020	10.780	1.06	1800	330
Louvre-28 *	AO 20 425	Coll. Coiffard	14768	226	0.160	10.200	0.45	130	610
Louvre-29 *	AO 24 794	Coll. David-Weill	14773	3568	0.556	13.760	1.09	60	2260
Louvre-30 *	AO 18 672	Citroën "Croisière jaune"	14784		12.400	0.025	3.01	4760	1130
Louvre-31 *	AO 20 410	Coll. Coiffard	14785		9.400	0.002	7.68	2510	5860
Louvre-32 *	AO 16 598	Contenau-Ghirshman	14791		0.217	4.070	3.55	560	6730
Louvre-33	AO 20 411	Coll. Coiffard		4038	2.370	7.890	1.26	10	2210
		Early 2nd. mill. BCE							
Louvre-34 *	AO 20 394	Coll. Coiffard	14761	220	0.007	8.080	1.14	60	3380
Louvre-35 *	AO 20 417	Coll. Coiffard	14763	221	0.397	11.430	1.09	90	470
Louvre-36 *	AO 20 427	Coll. Coiffard	14769	227	0.265	3.240	0.90	40	1770
Louvre-37 *	AO 24 795	Coll. David-Weill	14770	3551	0.001	10.560	0.12	90	470
Louvre-38 *	AO 24 796	Coll. David-Weill	14771		0.510	10.370	0.75	150	1100
Louvre-39 *	AO 24 799	Coll. David-Weill	14772	3547	1.650	0.914	1.13	514	856
Louvre-40 *	AO 20 413	Coll. Coiffard	14786		0.058	11.040	2.28	140	1630
Louvre-41 *	AO 24 798	Coll. David-Weill	14789	3564	0.098	5.100	1.62	20	2410
Louvre-42	AO 16 061	Contenau-Ghirshman	14795		0.020	0.007	2.74	3560	90
Louvre-43	AO 18 686	Citroën "Croisière jaune"	14799	348	0.076	8.650	1.00	170	2240
		Uncertain							
Louvre-44 *	AO 13 894	Coll. Godard	14776	230	0.221	9.520	1.44	360	1690
Louvre-45 *	AO 13 895	Coll. Godard	14777	231	0.138	0.482	3.78	850	6610
Louvre-46 *	AO 16 059	Acquired 1931		4041	< 0.300	< 0.060	4.10	1000	13000
Louvre-47	AO 25 263	Don Foroughi 1973	14782	4025	0.245	0.490	3.54	2650	2020
Louvre-48	AO 25 264	Don Foroughi 1973	14783	4026	0.136	0.007	6.94	3340	7280

Ag [µg/g]	Ni [µg/g]	Bi [µg/g]	Co [µg/g]	Au [µg/g]	Zn [µg/g]	Type of object	Dimensions H. / L.	Pl.	Bibliography
1930	1824	284	135	5	1	axe	6.8 / 9.2	15	–
1280	2200	176	1	8	1	pick	7.8 / 19.0	15	–
1840	1170	270	153	9	1	axe	5.6 / 7.9	15	–
192	1720	750	98	9	1	axe	8.5 / 12.0	15	–
2360	2040	472	81	18	9	axe	6.5 / 8.8	15	–
850	6500	260	79	18	24	axe	6.4 / 8.2	16	–
700	250	70	53	12	18	axe	4.8 / 7.9	16	–
914	1030	70	1	8	1	votive hammer	– / 13.4	16	Amiet 1976: 15, nr. 17.
518	953	20	1	6	1	pick	– / 18.6	16	–
490	214	2010	48	19	1	axe	5.7 / 14.0	16	–
5860	2540	163	111	15	8	mace head	13.5 / -	16	–
670	240	3010	6	7	1	axe	7.9 / 12.1	17	–
24	393	241	394	5	1	axe	7.0 / 12.0	17	–
217	170	300	239	90	1	axe	7.4 / 9.8	17	–
72	14	815	14	2	1	axe	6.4 / 8.4	17	–
76	48	70	32	16	1	axe	6.9 / 17.8	17	Amiet 1976: 22, nr. 23.
317	2520	70	817	16	25	axe	6.7 / 19.5	18	Pope 1938: pl. 51B; Deshayes 1960: nr. 1392, pl. XX-9; Amiet 1976: 22, nr. 24.
2300	2740	70	287	5	1	axe	8.6 / 15.0	18	Pope 1938: pl. 49A; Calmeyer 1969: 183, fig. 153; Amiet 1976: 23, nr. 29.
140	6830	60	802	9	1	axe	8.1 / 10.4	18	–
17	2700	517	623	3	15	axe	7.8 / 11.1	18	Pope 1938: 281, pl. 49B, nr. III; Amiet 1976: 23, nr. 28.
1060	94	1320	18	1	1	vessel	10.2 / 6.3	18	–
120	2870	327	634	11	20	belt buckle	8.3 / 5.9	18	Crouwel 1972: 51, fig. 2.
297	1970	70	208	11	1	dagger	23.0 / –	19	–
322	3240	60	196	5	1	dagger	21.0 / –	19	–
5400	< 2000	–	–	–	< 3000	axe	– / 12.7	19	–
505	9090	60	518	9	31	toilet article	8.8 / –	19	–
310	4210	60	170	6	1	toilet article	5.9 / –	19	–

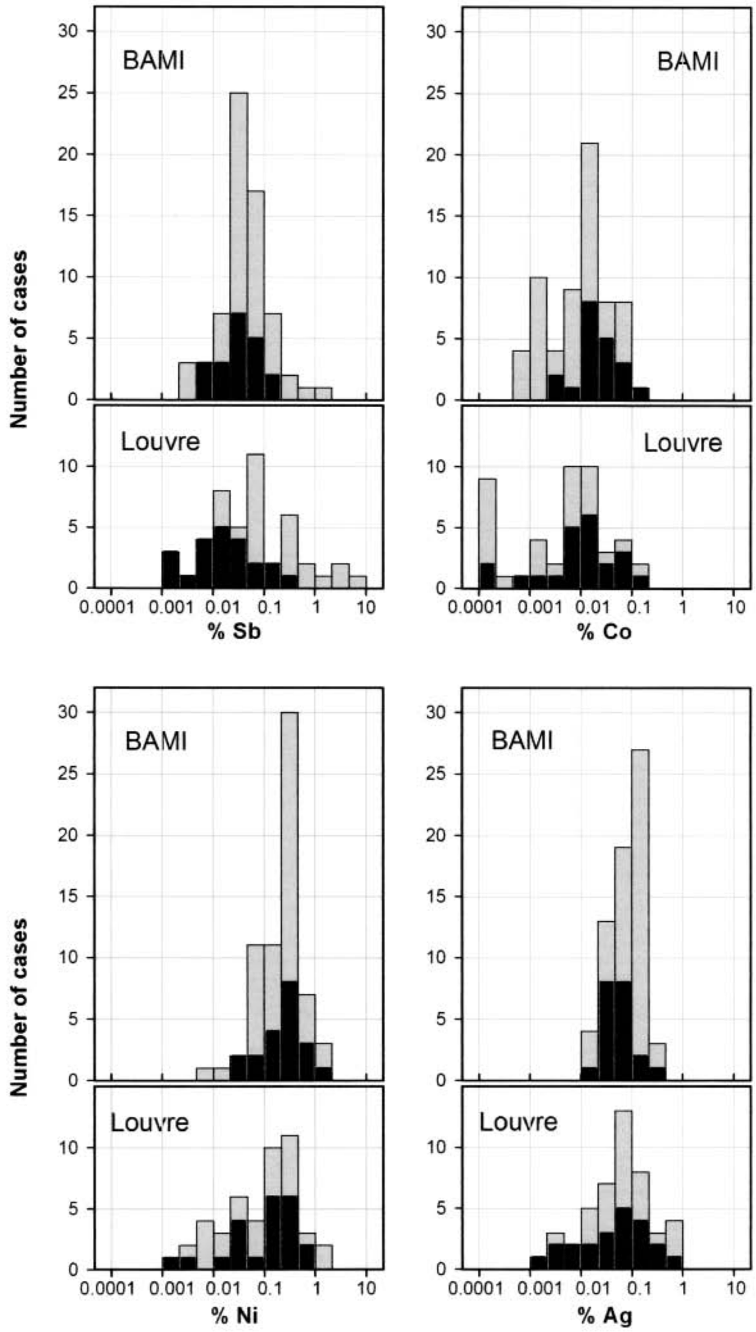


Fig. 6. Distribution of trace element concentrations [antimony (Sb), cobalt (Co), nickel (Ni) and silver (Ag)] among copper and bronze artefacts from Luristan. Samples retrieved during controlled excavations in the course of the BAMI project (upper parts in the four panels) are not significantly different from such acquired on the art market (Louvre collections), except for the subsidiary peak in the Louvre samples at around 0.0001 % Co the significance and meaning of which is not clear. Moreover, in both subsets are the distributions for the bronze objects (black bars) similar to those for the copper objects (grey bars) which suggests the bronze to have been manufactured by adding pure tin to copper as we have it in the copper objects. Judging from past experience at other Bronze Age sites this is rather the exception than the rule. (For details see text).

discussed above, all presently available data suggest in Luristan the bronze to have been made by adding tin to the low-arsenic fraction of the kind of copper as it is present in the non-bronzes. We shall come back to this problem in connection with the lead isotope results. We point out already now the implication that the tin used for alloying must have been very pure; since it can not have contributed notable amounts to any of the trace elements analysed for, it cannot have been contaminated with any of these elements.

The earliest, rather narrowly dated bronzes in our suite of objects are a bracelet (BAMI-1, Pl. 3) and a pin (BAMI-17, Pl. 5-6) from Bani Surmah together with a dagger from Mehr War Kabud (BAMI-39, Pl. 9). Although their precise age is somewhat uncertain (Table 4) they definitely are not younger than Phase III which, in Mesopotamia, runs to Late ED III/ Early Akkadian, in absolute terms about 2400/2300 BCE.

Lead Isotopy

A selection of 29 of the excavated BAMI objects (Tables 3, 4) and 40 specimens from the Louvre (Table 5) were analysed for the isotopic composition of their lead by means of thermal ionisation mass spectrometry (TIMS). For three of the daggers from the Louvre heft and blade were analysed separately. The results are presented as isotope abundance ratios relative to the abundance of ^{206}Pb.

a. Main Isotope Cluster

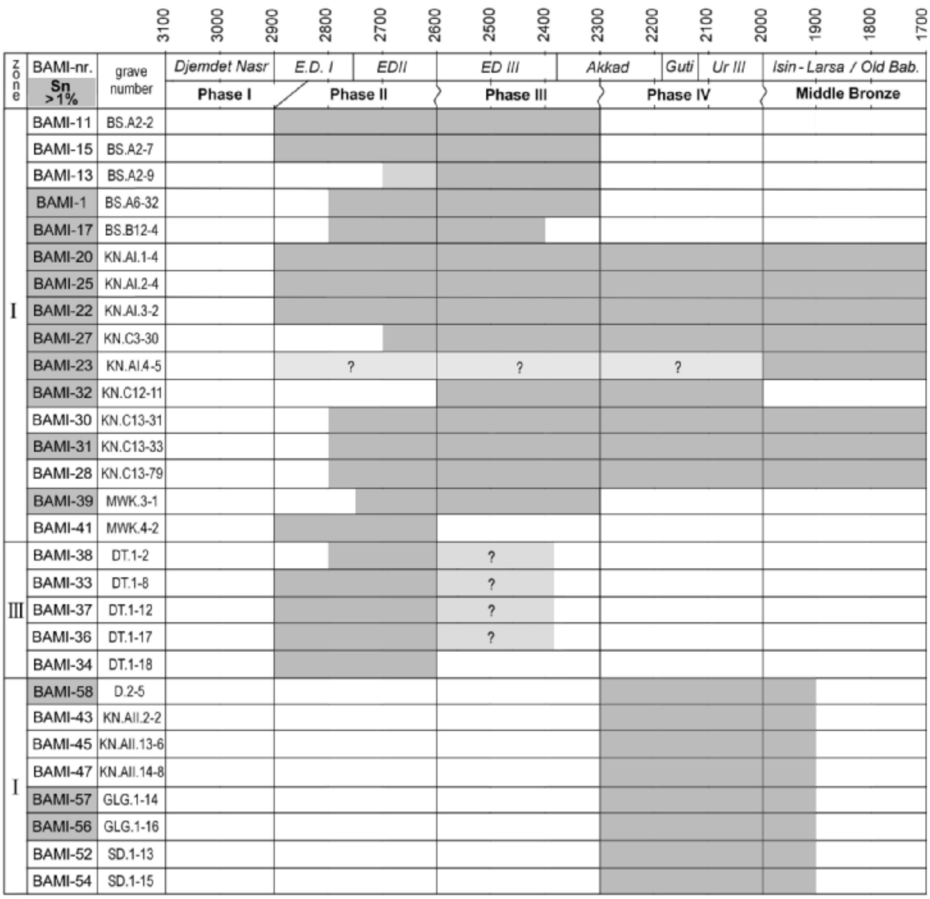
Almost one third of all artefacts analysed (20 out of 69) contain lead with very much the same isotopic composition (fig. 7). The cluster comprises objects from both sub-sets in our suite of samples, from the Louvre Collections as well as from the Belgian excavations. There are bronzes (13 out of 20) as well as non-bronzes and, among the bronzes, such with high tin content as well as such with low tin content. Axes and other implements are present as well as ornaments, like bracelets; and chronologically the members of the cluster date from Early Dynastic I-II to the early 2nd millennium BCE. The mean isotope abundance ratios of this group are ^{208}Pb/^{206}Pb= 2.0931±32, ^{207}Pb/^{206}Pb=0.8494±15 and ^{204}Pb/^{206}Pb=0.05426±15 where the listed “uncertainties” indicate the full range into which all ratios fall. Variations of such magnitude are well within the range observed for different ore

Table 3: Isotopic composition of lead in objects excavated in the course of the BAMI project.
Samples marked with an asterisk in column 8 belong to the Main Isotope Cluster (see text).

(1) Initials of site: (BS = Bani Surmah, DA = Darvand, DT = Dar Tanha, GLG = Gulu-lal-i Galbi, KN = Kalleh Nisar, MWK = Mehr War Kabud, SD = Sardant), followed by "Area" (if applicable: A, B, C or AII), tomb number and number of the object in the tomb.
(2) Metal: CuPb: Pb content above 2 %; CuAs: As content above 2%; Sn: Tin content above 1 %. Remark: the copper axe KN.AII.2-2 (BAMI-43) is made of folded sheet metal; all others shafthole axes are cast.

No.	Excavation No. (1)	Sample nos.	Object	Metal (2)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$	Plates
BAMI-11	BS.A2-2	17860	axe	Cu	2.0806	0.8393	0.05355	3, 4
BAMI-15	BS.A2-7	17864	axe	CuPbAs	2.0677	0.8290	0.05276	5
BAMI-13	BS.A2-9	17862	axe	CuPb	2.0800	0.8389	0.05346	3, 4
BAMI-1	BS.A6-32	17850	bracelet	SnPb	2.0922	0.8486	0.05428 (*)	3
BAMI-17	BS.B12-4	17866	pin	Sn	2.0948	0.8491	0.05423 (*)	5, 6
BAMI-20	KN.AI.1-4	17869	finger ring	Sn	2.0889	0.8418	0.05353	5
BAMI-25	KN.AI.2-4	17874	bracelet	Sn	2.0834	0.8430	0.05390	5
BAMI-22	KN.AI.3-2	17871	pin	Sn	2.1084	0.8700	0.05594	5, 6
BAMI-27	KN.C3-30	17876	dagger	Sn	2.0939	0.8510	0.05442	5, 6
BAMI-23	KN.AI.4-5	17872	bracelet	Sn	2.0876	0.8456	0.05395	5
BAMI-32	KN.C12-11	17881	spearhead	Sn	2.0860	0.8454	0.05395	5, 6
BAMI-30	KN.C13-31	17879	pin	Cu	2.0903	0.8519	0.05453	5
BAMI-31	KN.C13-33	17880	pin	Sn	2.0873	0.8449	0.05402	5
BAMI-28	KN.C13-79	17877	finger ring	Cu	2.1217	0.8746	0.05589	5
BAMI-39	MWK.3-1	17888	dagger	Sn	2.0920	0.8497	0.05422 (*)	9
BAMI-41	MWK.4-2	17890	dagger	CuAs	2.0780	0.8378	0.05345	9, 10
BAMI-38	DT.1-2	17887	axe	CuAs	2.0849	0.8433	0.05389	7, 8
BAMI-33	DT.1-8	17882	dagger	CuAs	2.0886	0.8450	0.05400	7, 8
BAMI-37	DT.1-12	17886	dagger	CuAs	2.0879	0.8437	0.05387	7, 8
BAMI-36	DT.1-17	17885	belt buckle	CuPbAs	2.0727	0.8338	0.05319	7, 8
BAMI-34	DT.1-18	17883	bracelet	Cu	2.0806	0.8418	0.05369	7, 8
BAMI-58	DA.2-5	17908	bracelet	Sn	2.1071	0.8635	0.05511	11
BAMI-43	KN.AII.2-2	17892	axe	Cu	2.1145	0.8663	0.05528	9, 10
BAMI-45	KN.AII.13-6	17894	axe	Cu	2.0796	0.8392	0.05352	9
BAMI-47	KN.AII.14-8	17896	pendant	CuAs	2.0732	0.8362	0.05341	9, 10
BAMI-57	GLG.1-14	17907	pin	Sn	2.0930	0.8486	0.05420 (*)	11
BAMI-56	GLG.1-16	17906	bracelet	Sn	2.0736	0.8376	0.05350	11
BAMI-52	SD.1-13	17902	bracelet	Cu	2.1048	0.8590	0.05483	11
BAMI-54	SD.1-15	17904	bracelet	Cu	2.1057	0.8589	0.05478	11

Table 4



specimens from a single occurrence[3]; we therefore suggest that a single ore deposit has supplied, over an extended period of time, a good fraction of the copper utilized in Luristan. The conclusion has to be qualified, however, because a fair number of the artefacts belonging to this isotope group is lead-rich. According to the criterion that copper with a lead content of 2 %

[3] Isotope abundance ratios among ores from a single occurrence may vary within wide limits, in special instances up to several percent; in the vast majority of cases the spread is less than ±0.4 % (see, e.g., Begemann & Schmitt-Strecker 2007: fig. 2). This undeterminedness has to be taken into account when looking for ores that "match" the isotopic composition of the lead in an artefact.

Table 5: Lead isotopic composition of “Luristan” artefacts acquired on the art market and now in the Louvre, Paris. Samples marked with an asterisk belong to the Main Isotope Cluster (see text).
(#) CuPb: Pb content above 2 %; CuAs: As content above 2 %; Sn: Tin content above 1 %.

No.	Sample numbers	Inv. No. Louvre	Object	Metal (#)	^{208}Pb/^{206}Pb	^{207}Pb/^{206}Pb	^{204}Pb/^{206}Pb	Plates
	Early Dynastic III							
Louvre-1	14 774 4031	AO 20 436	mace head	CuPb	2.0947	0.8460	0.05404	12
Louvre-3	14 778 I 232 I	AO 14 054	dagger, haft	Cu	2.0826	0.8398	0.05349	12
	14 778 II 232 II		, blade	CuAs	2.0801	0.8382	0.05337	
Louvre-5	14 780 3541	AO 20 451	vessel	CuAs	2.0856	0.8444	0.05399	12
Louvre-6	14 787 3542	AO 24 013	axe	CuAs	2.0834	0.8418	0.05372	12
Louvre-7	14 790	AO 13 906	mace head	CuPbAs	2.0949	0.8468	0.05403	13
Louvre-8	14 792	AO 20 435	mace head	Cu	2.0794	0.8398	0.05358	13
Louvre-9	14 793 3552	AO 24 792	mace head	CuAs	2.0840	0.8454	0.05390	13
Louvre-10	14 794	AO 13 916	vessel	CuAs	2.0869	0.8436	0.05385	13
Louvre-12	14 798	AO 14 056	rein ring	CuPbAs	2.0760	0.8375	0.05357	13
Louvre-13	4028	AO 21 635	vessel	CuAs	2.0749	0.8371	0.05327	13
Louvre-14	4029 I	AO 16 603	dagger, haft	CuPbAs	2.0963	0.8500	0.05429 *)	14
	4029 II		, blade	CuAs	2.0947	0.8475	0.05412	
Louvre-15	4030 I	AO 18 663	dagger, haft	CuAs	2.0941	0.8492	0.05424 *)	14
	4030 II		, blade	CuAs	2.0940	0.8495	0.05429 *)	
	Akkadian/ Ur III							
Louvre-16	14 753 212	AO 11 985	axe	Sn	2.0813	0.8419	0.05392	14
Louvre-17	14 754 213	AO 11 986	axe	Sn	2.0821	0.8525	0.05435	14
Louvre-18	14 755 214	AO 13 883	axe	CuAs	2.0933	0.8500	0.05428 *)	14
Louvre-19	14 756 215	AO 13 884	axe	Sn	2.0945	0.8503	0.05430 *)	14
Louvre-20	14 757 228	AO 13 885	pick	Sn	2.1110	0.8650	0.05530	15
Louvre-21	14 759 218	AO 18 670	axe	CuPbAs	2.0913	0.8497	0.05440 *)	15
Louvre-22	14 760 219	AO 18 671	axe	Sn	2.0927	0.8494	0.05425 *)	15
Louvre-23	14 762 229	AO 20 408	pick	Sn	2.1020	0.8533	0.05441	15
Louvre-24	14 764 222	AO 20 420	axe	Sn	2.0920	0.8488	0.05422 *)	15
Louvre-25	14 765 223	AO 20 421	axe	CuPb	2.0922	0.8498	0.05430 *)	15
Louvre-26	14 766 224	AO 20 422	axe	Sn	2.0828	0.8440	0.05401	15
Louvre-27	14 767 225	AO 20 423	axe	Sn	2.0763	0.8367	0.05343	16
Louvre-28	14 768 226	AO 20 425	axe	Sn	2.0932	0.8482	0.05416 *)	16
Louvre-29	14 773 3568	AO 24 794	votive hammer	Sn	2.0912	0.8486	0.05414 *)	16
Louvre-30	14 784	AO 18 672	pick	CuPbAs	2.0928	0.8501	0.05427 *)	16
Louvre-31	14 785	AO 20 410	axe	CuPbAs	2.0916	0.8499	0.05422 *)	16
Louvre-32	14 791	AO 16 598	mace head	SnAs	2.1050	0.8604	0.05507	16

No.	Sample numbers		Inv. No. Louvre	Object	Metal (#)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$	Plates
	Early 2. mill. BCE								
Louvre-34	14 761	220	AO 20 394	axe	Sn	2.0776	0.8391	0.05345	17
Louvre-35	14 763	221	AO 20 417	axe	Sn	2.0831	0.8426	0.05381	17
Louvre-36	14 769	227	AO 20 427	axe	Sn	2.0928	0.8488	0.05419 *)	17
Louvre-37	14 770	3551	AO 24 795	axe	Sn	2.0910	0.8495	0.05440 *)	17
Louvre-38	14 771		AO 24 796	axe	Sn	2.1127	0.8765	0.05652	18
Louvre-39	14 772	3547	AO 24 799	axe	Cu	2.0819	0.8407	0.05361	18
Louvre-40	14 786		AO 20 413	axe	SnAs	2.0901	0.8464	0.05413	18
Louvre-41	14 789	3564	AO 24 798	axe	Sn	2.0953	0.8494	0.05425 *)	18
	Uncertain								
Louvre-44	14 776	230	AO 13 894	dagger	Sn	2.1073	0.8622	0.05513	19
Louvre-45	14 777	231	AO 13 895	dagger	CuAs	2.1090	0.8628	0.05503	19
Louvre-46		4041	AO 16 059	axe	Cu	2.0776	0.8391	0.05359	19

or more is an intentional alloy there are six such alloys in the Main Isotope Cluster. For these the lead isotope signature characterises the *lead* ores from which the lead derives, not the lead as it will have been associated with the copper ores. Moreover, the suggestion that a single ore occurrence, whether one of copper or lead, had supplied this metal is not compelling. The possibility cannot be excluded, e.g., that there are several different ore deposits with the same isotopic fingerprint which then were exploited consecutively. And such constancy in the lead isotopic composition and the trace element contents one expects also if the artefacts in question were a single batch of counterfeit objects!

Another observation worthy of comment is that 13 of the 20 artefacts in the Main Isotope Cluster are (tin)bronzes. For them to be indistinguishable isotopically from the copper objects suggests that this bronze was made by adding tin to the kind of copper as it is present in the local copper (and arsenical copper) objects. This point is not trivial. Indeed, previous experience, at Poliochni on Lemnos (Pernicka et al. 1990), in Bulgaria (Pernicka et al. 1997), at Beşiktepe (Troia) (Begemann et al. 2003) and in the western Balkans (Schmitt-Strecker & Begemann 2005), tended to show the opposite in that the bronze out of which local artefacts are made can *not* have been manufactured by alloying tin with the kind of copper as it is present in the local contemporaneous objects made of unalloyed copper. In the present instance, as mentioned already, the isotope

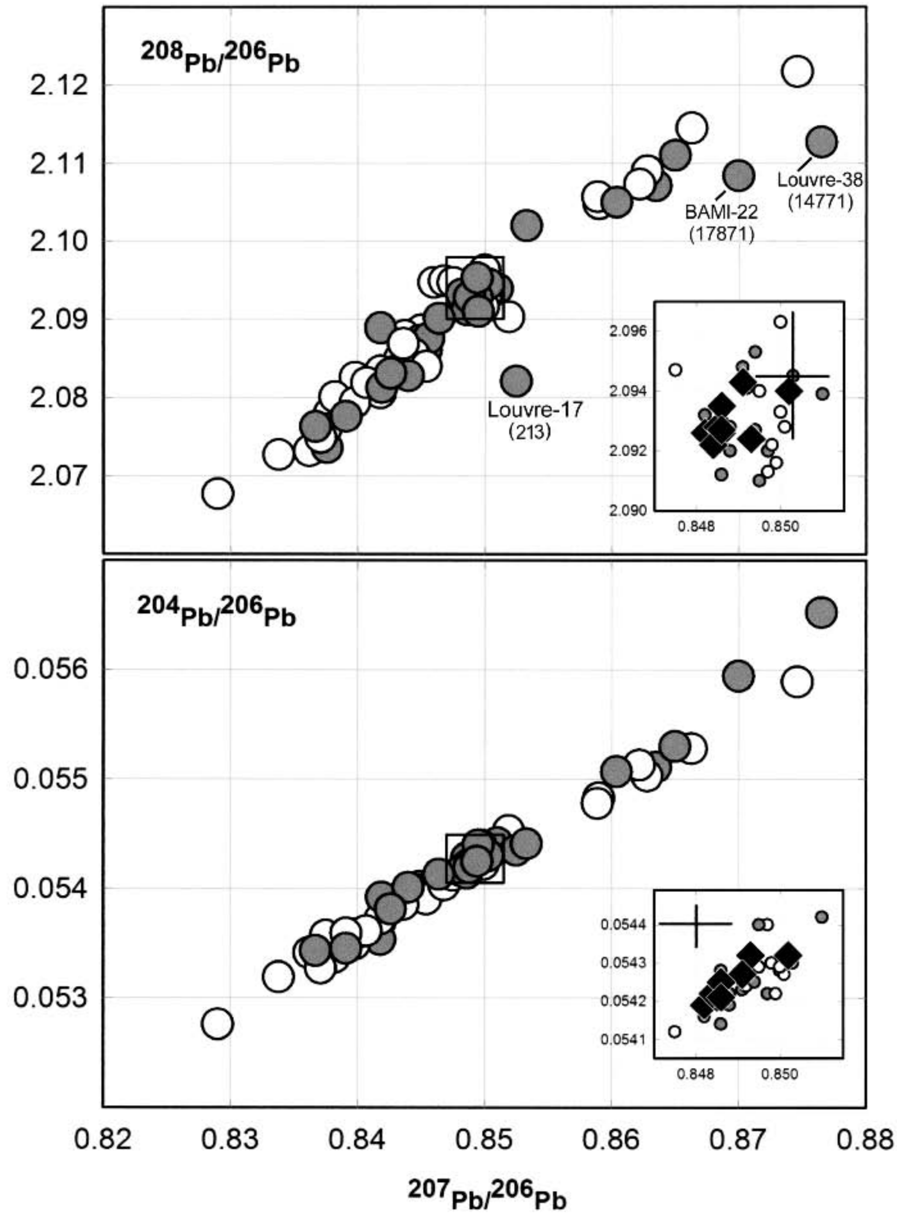


Fig. 7. Three-isotope plots of the lead isotopic composition in Luristan copper-base artefacts [Open symbols: Cu, CuAs, CuPb; grey: CuSn (bronze)]. The inserts are enlargements from the main diagram showing the data for a group of 20 objects with very similar isotopy (Main Isotope Cluster, see text). Also shown in the inserts, as diamonds, are the isotopic compositions of lead in copper ores from occurrences at Ahangaran, at Shamsabad and Deh Hosein south-west of Arak, some 250 km NE of Luristan, which qualify as potential sources of the metal. The crosses in the inserts mark the experimental uncertainties associated with the mass spectrometric determination of the isotope abundance ratios which are ±0.1 % on the 96 % confidence level.

evidence for a common source of the copper in the bronzes and the non-bronzes is supported by the chemical data.

The nearest ore occurrences with lead matching the isotopic composition of the Main Isotope Cluster are known from Ahangaran (2.0940; 0.8502; 0.05432) and from Shamsabad (2.0924; 0.8493; 0.05432), west and south-west of present-day Arak, respectively. (For a summary of all potential ore sources see fig. 13). While these mineralisations primarily are of lead/zinc and iron, respectively, at both sites copper ores are sufficiently abundant to have filled the need of prehistoric people for a long time. A further occurrence with matching lead isotope signature has recently been reported to exist at Deh Hosein, near Shamsabad (Momenzadeh et al. 2002; Nezafati et al. 2006). At present, the deposit is of no commercial importance - Deh Hosein is not among the 532 sites listed in the official Mineral Distribution Map of Iran published by the Geological Survey of Iran and containing all information available up to 1974 — but the authors report prehistoric mining activities to have left behind "huge waste dumps", dating to the first half of the 2nd millennium BCE, at least (Nezafati et al. 2006). What makes this mining site particularly exciting is the occurrence of copper ores together with ores of arsenic and of tin so that this single site could have supplied the starting material for the arsenical copper as well as for the bronze of the artefacts in the Main Isotope Cluster. Indeed, Nezafati et al. (2006) suggest Deh Hosein as a possible source for the tin in Luristan bronze.

The polymetallic mineralisations at Deh Hosein occur in veins and veinlets as well as disseminated in meta-sedimentary rocks (Nezafati et al. 2006). The chemical composition of pieces of these ores is quite variable, depending on the relative proportions of the various kinds of ore minerals present. Without careful separation and selection of one kind of ore or the other the metal smelted from such mixtures will show a range in chemical compositions distributed around some average value. This is exactly what is being observed for the arsenic content of the copper and bronze artefacts from the Main Isotope Cluster, with their putative provenance from Deh Hosein, which shows a single-mode distribution between 0.1 % and ca. 8 % of arsenic (fig. 8, upper panel). For tin, however, the situation is different. In the non-bronzes its concentration ranges between 20 and 2200 microgram per gram and thus is ten times lower, at least, than the lowest tin content of any of the bronzes (fig. 8, lower panel). Such a distinct bimodal distribution is contrary to what one expects to result from the indiscriminate smelting of polymetallic ores, whether from Deh Hosein or

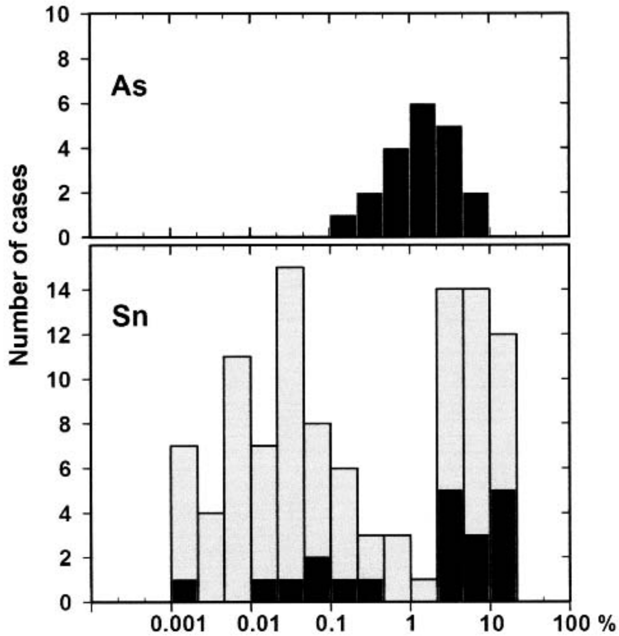


Fig. 8. The tin content of copper-base artefacts from Luristan exhibits, on a logarithmic scale, a distinct bi-modal distribution as it is expected if the bronzes are deliberate copper-tin alloys (lower panel). If extensive remelting has occurred, copper and bronze scrap must have been carefully kept apart and been processed separately. Note that objects belonging to the Main Isotope Cluster (marked in black) show the same separation into two well-distinct groups. Since the lead isotope evidence suggests that the bronze objects in this group might derive from "local" copper and tin ores from the same occurrence (in the eastern part of the central Zagros Mountains) the two kinds of ores must have been well-separated during all stages of mining and smelting. The opposite is observed for the arsenic contents in the same objects (upper panel); they exhibit the single-mode distribution as it results from indiscriminate co-smelting of arsenic ores and copper ores.

any other occurrence where the respective ores are closely associated with one another. The distribution rather implies that tin ores were separated effectively from all others and were kept separate during all steps of smelting and manufacturing of the artefacts. It will be interesting to see whether future work at Deh Hosein will bring to light any evidence for a beneficiation of the ores with respect to their tin minerals. Of course, nature itself might have taken care of such an enrichment by weathering tin ores and concentrating the cassiterite in creeks or rivers, fed by run-off from the Deh Hosein ore field, from where the tin ores were then recovered and utilized

for alloying. But independent of whether the technical feasibility existed for a beneficiation of the ores or whether one relied on nature to have done this, there is no obvious reason why one should have wanted to keep all but traces of tin out of the copper and arsenical copper.

Unfortunately, the assignment of the Main Isotope Cluster to nearby ore occurrences is not unique. There are other deposits with isotopically very similar lead which also qualify as potential sources for the metal. While none of them fits quite as well as do the sources from near Arak the variations in the isotopic signature usually encountered among different samples from the same ore occurrence nevertheless makes them viable candidates. Of these, the ores from Anatolia, at Kayabasi Köyü, Küre and Madenli/Çayeli near the Black Sea coast (Seeliger et al. 1985; Wagner et al. 1989), can presumably be ignored. Although the latter two occurrences are reported to have been exploited in prehistoric times (Wagner & Öztunali 2000) they pose the same problems as all Anatolian copper ores in that their arsenic content is way too low. The other isotopically matching sources, at Shaida, in Western Afghanistan southwest of Herat, as well as several occurrences in the Northern Caucasus (Artanskoje, Belokanskoje, Sadon), are possibly different in this respect. We are not aware, however, of any systematic investigation of these ores for the minor and accessory minerals they are associated with so that, for the time being, it is not clear whether the concentrations of minor and trace elements in copper smelted from these ores would match the concentrations observed in the artefacts.

b. Ratios lower than Main Isotope Cluster

There are 36 objects with ^{206}Pb-normalized abundance ratios falling to the lower left of the main cluster in both partial presentations of fig. 7. Among them are again all kinds of metal, bronzes and non-bronzes, lead-poor objects and lead-rich CuPb alloys. A clustering is not apparent (fig. 9), neither according to the type of metal the artefacts are made of nor according to their antiquity. Potential sources of copper and lead with matching isotope abundance ratios exist on the Central Iranian Plateau (fig. 13) at Veshnoveh, halfway between Kashan and Qom, at occurrences another 250 km further to the south-east in the mining district of Anarak (Baghorq, Chahmileh, Khuni, Nakhlak) and, for the Early Dynastic belt buckle from Dar Tanha (BAMI-36 = Lab. No. 17 885), at Bezarak/Bozaruk in the Hindukush Mountains of East Afghanistan. (Isotope data are from own unpub-

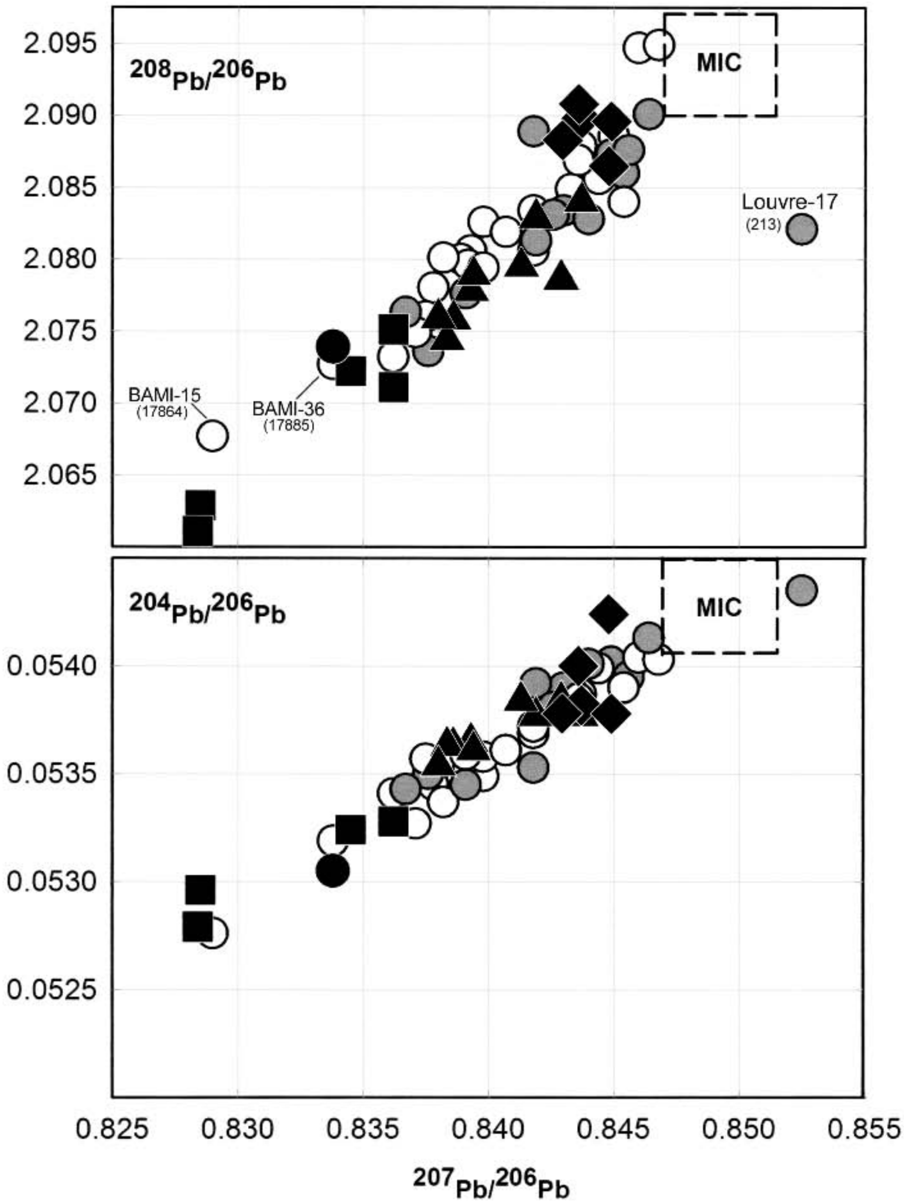


Fig. 9. Lower-left part of fig. 7. Plotted also, as black symbols, are ore data from Veshnoveh/Karkas (▲), Anarak (◆), Ergani/Mamlis (■), and Bozaruk/Bezarak (Hindukush) (●) which are potential sources for the metal. Experimental uncertainties are about the size of the symbols. The boxes to the upper right marked MIC show the narrow field populated by the 20 objects of the Main Isotope Cluster. (For details see text).

lished measurements and from Pernicka et al. 2006). Together, the mineralisations from these districts cover all but two of the artefacts (fig. 9). As is evident from fig. 9 the copper ores from Anarak (upper right) fit only a minor portion of the objects. The suggestion of Pigott (1999: 113) that during the Neolithic and Chalcolithic on the Iranian Plateau the arsenic-rich copper deposits at Anarak should have supplied the metal "perhaps to the exclusion of other available deposits" clearly does not apply to Luristan towards the end of the 3rd millennium BCE.

The two exceptions not covered by ores from the Iranian Plateau and Afghanistan are an arsenic-rich (2.5 % As) axe from Bani Surmah (BAMI-15 = Lab. No. 17864) and a bronze axe from the Louvre collections (Louvre-17 = Lab. No. 213). Of these, the latter is a "chemical maverick" also, with extremely low contents of antimony (20 µg/g) and lead (30 µg/g), combined with a very high silver content of 0.34 %. What makes its isotopic fingerprint so exceptional is evident from the top panel of fig. 7 where the data point plots way below the general trend line as it is defined by the other samples. The reason for this deviation is a deficit, relative to ^{206}Pb, in these samples, of ^{208}Pb which is the decay product of thorium. Apparently, (part of) the radiogenic lead in these objects was produced in an environment with a lower — than — normal thorium/uranium ratio, most likely within the ore(s) that served as source of the metal.

The axe from Bani Surmah (BAMI-15 = Lab. No. 17864), on the other hand, is one of three axes from the same grave which is quite unobtrusive as far as its contents of minor and trace elements is concerned. The lead isotope abundances make it fall at the extreme lower left in fig. 9. Copper ores and slags with matching isotopy exist at Ergani and Mamlis in Eastern Anatolia (Seeliger et al. 1985; Wagner et al. 1989) and in the Bolgardağ valley of the Central Taurus (Yener et al. 1991) but for all of them there is again the problem of the missing arsenic in these ores which, in the present instance, is aggravated by the fact that the axe is made of *arsenical* copper.

c. Ratios higher than Main Isotope Cluster

The remaining 12 artefacts plot to the upper right from the Main Isotope Cluster (fig. 10). Notably absent from this group are objects unambiguously older than Phase IV, i. e., older than Akkadian/Ur III. Apparently, new

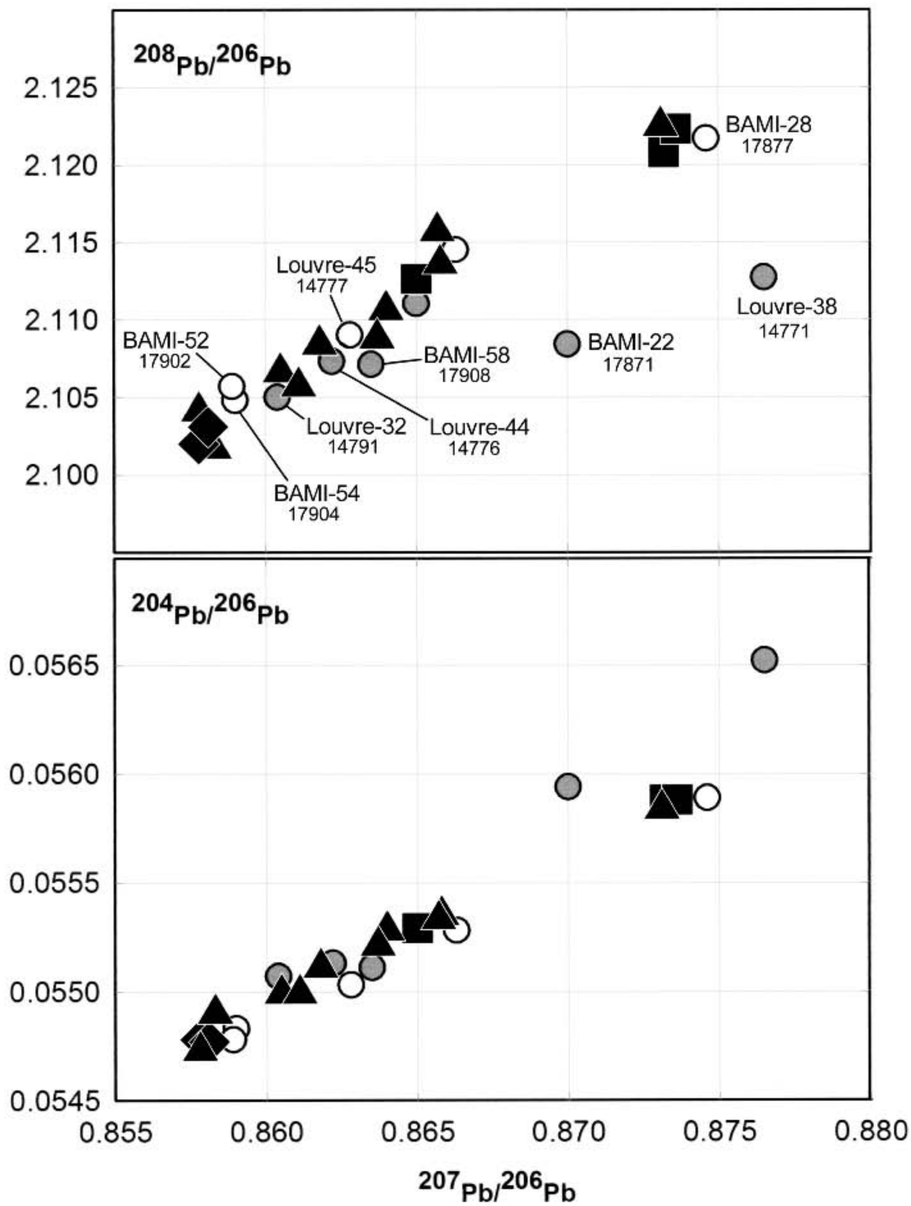


Fig. 10. Upper-right part of fig. 7 together with isotopically matching ores. Mushiston, Tadzhikistan (◆), Anatolia (■), Timna, Israel (▲).

sources of copper became available in Luristan towards the end of the 3rd millennium BCE. Interestingly, the high ratios again are not restricted to any one kind of metal; seven of the artefacts are bronzes and five are unalloyed copper. Of the latter, two copper bracelets from grave 1 at Sardant (BAMI-52 = Lab. No. 17 902; BAMI-54 = Lab. No. 17 904) are indistinguishable from one another in their lead isotopy. Since they also have virtually identical contents of trace elements there can be no reasonable doubt that their copper derives from the same ore occurrence. Actually, considering their dimensions they most likely derive from a single copper rod from the same furnace charge. Potential source ores for copper with such an isotopic fingerprint, and also for a bronze mace head from the Louvre collections (Louvre-32 = Lab. No. 14 791, Pl. 16), exist at Mušiston, Tadžikistan. This is a particularly intriguing possibility since, like Deh Hosein in Western Iran, it is also a copper/*tin* occurrence with clear evidence for prehistoric exploitation (Alimov et al. 1998).

Another triplet of objects where all isotope abundance ratios agree well within the experimental uncertainties of ±0.1 % (96 % confidence level) are an (excavated) fragment of a bronze bracelet from Darvand A (7.1 % Sn; BAMI-58 = Lab. No. 17 908, Pl. 11) and two daggers from the Louvre — one made from bronze with 9.5 % tin (Louvre-44 = Lab. No. 14 776, Pl. 19) and another made from arsenical copper (3.8 % As; Louvre-45, Lab. No. 14 777, Pl. 19). For them we know of no nearby copper ores with a matching isotope signature that might have served as source of this copper. The nearest such ores exist at Timna, south of the Dead Sea on the western side of the Arabah rift valley in present-day Israel (Gale et al. 1990; Hauptmann 2000). We mention this just for the sake of completeness, not to suggest such a provenance to be a likely possibility. Presumably, the apparent lack of more plausible candidate occurrences simply reflects the incomplete coverage of closer-by regions as far as the characterisation of their copper ores by the isotopic composition of their lead is concerned.

The artefact in the present study with the highest $^{208}Pb/^{206}Pb$ abundance ratio is a small copper ring from Kalleh Nisar (BAMI-28 = Lab. No. 17 877, Pl. 5). Its copper possibly derived from occurrences at Horzum in the Bolgardağ mountains of the Eastern Taurids (Hirao et al. 1995; Wagner et al. 2003). And finally there are two objects that contain lead with isotopic compositions that have not (yet) been encountered in any of the ores and artefacts analysed so far. The objects are made of bronze, Lab. No. 14771 is an axe from the Louvre collections (Louvre-38, Pl. 18) and Lab. No. 17871 is

an unobtrusive pin from Kalleh Nisar (BAMI-22, Pl. 5, 6). In both cases the data points plot off the trend lines determined by the other samples so that the abundance ratios cannot be explained as a mixture of two or more of the "normal" compositions as they occur in the other samples[4]. The deviation from the general trend is most pronounced in the upper panel of figs. 7 and 10; it is the same as discussed above for another bronze axe from the Louvre (Louvre-17, Lab. No. 213, Pl. 14) in that there is again a deficit of ^{208}Pb from the radioactive decay of thorium or, alternatively, an excess of ^{206}Pb from the decay of uranium. The provenance of such lead is completely enigmatic at present which serves as a reminder that as far as the isotopic and chemical analyses of copper ores are concerned the coverage of most regions in the Near East is spotty at best.

Discussion

In the material features like minor and trace element contents and the isotopic composition of their lead we see no significant differences between the group of excavated objects and the suite of artefacts acquired on the art market. These data leave no room for doubt that the acquired objects should be made of genuine Luristan copper and bronze. But, of course, the data cannot contribute to the question whether simple shapes or scrap metal have been recast, at possibly very recent times, into the intricate, much higher-valued true objects of art as we have them today.

We also see no difference in the material features between the (excavated) objects from the Pish-i Kuh-related "zone III" and the remainder of the excavated specimens from the Mesopotamia-related "zone I" (fig.1). The cultural orientation does not seem to be reflected in the material the objects are made of although, admittedly, one wishes the number of objects to be larger in order to make this conclusion more significant.

A comparison of the present Luristan lead isotope data to those obtained on contemporaneous objects from Mesopotamia (Begemann & Schmitt-Strecker 2008) shows the range in abundance ratios to be considerably

[4] In presentations of the lead isotope data as chosen here two-component mixtures of lead always fall on the tie line connecting the two end members; if three or more different types of lead are mixed together the resulting mixture falls inside the polygon defined by the respective end members.

wider in Mesopotamia. As an illustration of this point we have chosen, in fig. 11, the $^{207}Pb/^{206}Pb$ ratios, but the same is true for all other abundance ratios as well. To the extent that a variety in abundance ratios reflects a

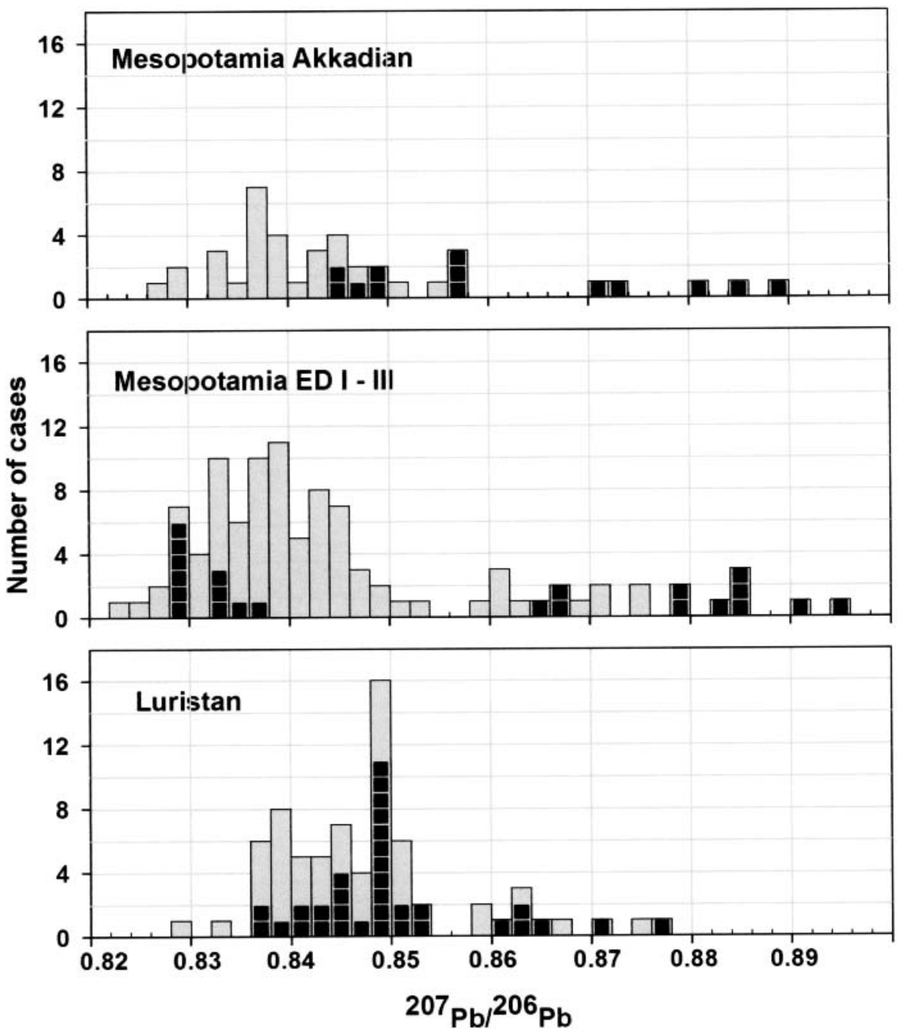


Fig. 11. The prominent peak in the distribution of $^{207}Pb/^{206}Pb$ abundance ratios at around 0.850 observed in copper-base artefacts from Luristan (lower panel) is almost completely absent in contemporary Mesopotamia. Since the peak is due entirely to objects from the Main Isotope Cluster which arguably owe their metal to "local" ores, such ores apparently did not reach Mesopotamia. Vice versa, bronzes (filled symbols) with high $^{207}Pb/^{206}Pb$ ratios ≥ 0.878 did not reach Luristan.

variety of sources Mesopotamia received its copper and bronze from a wider variety of sources than did Luristan — a result which, surely, is no real surprise.

In detail the frequency distributions for Luristan and Mesopotamia are different in two important respects. First, the pronounced maximum in Luristan at $^{207}Pb/^{206}Pb$ values of around 0.850 (lower panel) coincides with an equally pronounced minimum in the distribution curve at the same value in Mesopotamia. Since, in Luristan, this maximum is defined by objects belonging to the Main Isotope Cluster this kind of lead is obviously missing from among the artefacts from Mesopotamia. Recalling the assignment of this isotope signature to copper occurrences near present-day Arak, and to the copper/arsenic/tin ores from Deh Hosein in particular, we suggest that ores from these occurrences in the eastern part of the Central Zagros Mountains were quite important providers for Luristan but did not play any visible role in the Mesopotamian lowlands.

The second important distinction concerns the isotopic composition of lead in bronzes. Among the 33 Luristan bronze objects analysed there is not a single one with a $^{207}Pb/^{206}Pb$ ratio higher than 0.878 (fig. 11). In ED III-Mesopotamia, on the other hand, such cases are known from Hafagi, north-east of present-day Baghdad, and from the Royal Cemetery of Ur; from the Akkadian period we know one such bronze each from Gawra in the North, from Nippur, and from Ur in the South. The provenance of lead with such high abundance ratios is still obscure, independent of whether the lead is assumed to have been associated with the tin used for alloying, or to have been carried with the copper. And, as mentioned above, assuming the lead to be a mixture of two components does not solve the problem but rather aggravates it because, in this case, one of the putative components would have to have been even more extreme in its isotopic composition than the mixture.

Based on the presently available data the most plausible source region seems, to us, to be southern Rajasthan/northern Gujarat from where isotopically matching ores have been reported by Ericson & Shirahata (1985) and by Srinivasan (1999). Moreover, it is a region where "copper and tin ores occur in proximity" (Hedge 1978: 42; Chakrabarti 1979: 63) so that the necessary ingredients for making bronze with the right lead isotope fingerprint are available. Presumably, this bronze will have reached Mesopotamia by sea via Dilmun/Bahrein in the Persian Gulf (see, e. g., Muhly 1995; Muhly and Stech 2003) possibly leaving traces

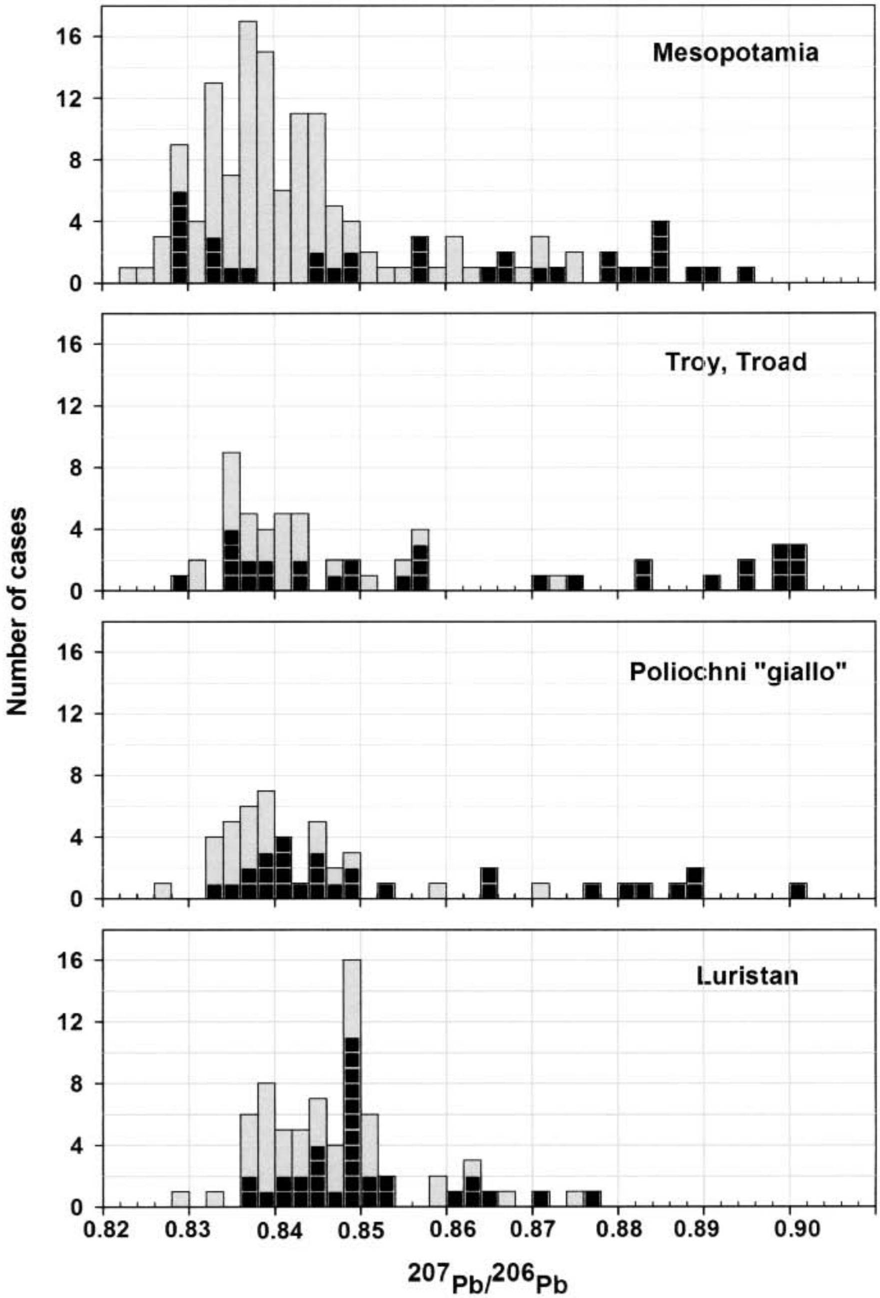


Fig. 12. In marked contrast to the situation in Luristan towards the end of the 3rd millennium BCE bronze objects (filled symbols) with high-abundance-ratio lead make up a major fraction of the total at Poliochni on Lemnos in the northern Aegean, in the Troad, and in Mesopotamia. (Adapted from Begemann et al. 1989).

of such trade at the entrance to the Gulf at Tell Abraq, United Arab Emirates (Weeks and Collerson 2004). In all probability it was then also traded from Mesopotamia into the northern Aegean and the Troad. Such a possibility is at least suggested by the observation that at Poliochni on Lemnos, during period "giallo" which dates to around 2300-2200 BCE (Pernicka et al. 1990), and among the bronze artefacts from Troia and the Troad (Pernicka et al. 1984; Stos-Gale et al. 1984) the high isotope abundance ratios are again an outstanding feature (fig. 12). In the absence of evidence to the contrary, and given the difficulties with identifying any ore sources with such high abundance ratios, we assign these artefacts to ores from the same source region as those which provided the copper in Mesopotamia.

We find it remarkable that in Luristan this isotopic signature should be completely absent. Admittedly, our knowledge of prehistoric Luristan is very limited. Even in Pusht-i Kuh, archaeologically the best documented area of Luristan, we know hardly anything about the ethnic or socio-economic context. The significance of the three cultural zones in the Pusht-i Kuh, although well visible in the material culture, remains to be explained. Since our data are only provided by a limited number of tombs, unevenly distributed over the region, it remains difficult, if not impossible, to visualise the socio-economic structure of third millennium Luristan society (Haerinck & Overlaet 2006: 68-70). The three Pusht-i Kuh zones may very well represent "tribal zones", but whether the population had a full nomadic, semi-nomadic or sedentary lifestyle remains unknown. A semi- and full nomadic way of life with an economy based on some rain-fed agriculture and the herding of sheep and goats, co-existing with pockets of small settled communities is a combination which is well documented in the region in more recent times. It is well possible that the situation during the Early Bronze Age was not all that different.

Mounds are rare in Pusht-i Kuh, however, and none has ever been sounded or excavated. Some are known to exist in the Aivan, Ilam and Chavar areas (zone I), and in Shirvan-Chardaval (zone III) (Haerinck & Overlaet 1999: 1, ill. 1), but most of these are relatively small and can not represent any extensive settled society. At the same time, one has to keep in mind that little research has been focused on settlements. Our concept of the settlement patterns in Luristan may be much distorted as villages are often located on the lower slopes of mountains, close to springs providing fresh water. Such locations are likely to be covered by sediments, making

their detection difficult. Larger mounds are to be found on the fringes of Luristan in the direction of the Mesopotamian plain, from the Hamrin/Diyala region (where scarlet ware was abundant) to the Badrah area (some 20 km across the Iraqi border, see Hrouda 1973) along the major road between Babylonia and Elam.

Economic relations between the two regions are thus to be expected and the presence of Mesopotamian imports in Pusht-i Kuh zone I is, simply from a geographical point of view, almost self-evident. Zone I is characterised by Mesopotamian imports such as seals and painted pottery. Stylistically, the bronze finds from this region have for the most part direct Mesopotamian comparisons, to such an extent that it has been suggested repeatedly that most were likely imported into the Pusht-i Kuh (Haerinck & Overlaet 2006: 67). It is therefore all the more puzzling not to see more of these manifold interactions between Luristan and Mesopotamia reflected in the material features of the *metal* objects analysed. Assuming the interaction to have been purely one of inspiration, rather than an exchange of goods, might be an explanation although, given the proximity, it is presumably not a likely one. Of course, this puzzle is not contingent upon where ultimately the source of the copper-base metal may have been. Had it reached Mesopotamia via land the lack of any close connection would be equally baffling.

This apparent contradiction thus remains to be explained. It is evident that when items such as seals and even pottery of Mesopotamia reached zone I, also metal objects will have done so. Like with the painted "scarlet ware" potteries, where Mesopotamian imports as well as local imitations and Mesopotamian-inspired vessels occur, one expects metal objects of Mesopotamian origin as well as local copies to be found next to one another. Other metal artefacts, such as the ring-shaped pendants (BAMI-46 and 47; Lab. Nrs. 17 895 and 17 896, zone I, EBA IV, Pls. 9, 10), which have no Mesopotamian comparison whatsoever, are clearly local items. One of them was isotopically analysed and, incidentally, is not conspicuous in the isotopic composition of its lead or its trace element contents.

The fact that a good fraction of the ores used for the smelting of Luristan copper derive from sources other than those used for the Mesopotamian copper, is indicative of the importance of local production centres. The cost of the ores, or their more reliable supply, may be reasons why, in Luristan, one relied on different metal sources than in Mesopotamia. On the other hand, the total absence among the analysed Pusht-i Kuh artefacts of the

isotopically conspicuous high abundance-ratio bronzes which are prominent in Mesopotamia may, to some degree, be accidental. Although the majority of the tested artefacts do come from zone I where Mesopotamian imports are most likely, the number of analyses remains altogether limited which makes any conclusions subject to the limitations of poor statistics. Actually, in this respect the situation is not quite as bad as the present data might suggest. Nezafati et al. (2007) have analysed the lead isotopy of another 20 bronze objects from Luristan — possibly not all of indubitable provenience and many younger than Middle Bronze Age; they report the highest isotope abundance ratios to be $^{208}Pb/^{206}Pb \approx 2.10$; $^{207}Pb/^{206}Pb \approx 0.860$; $^{204}Pb/^{206}Pb \approx 0.0549$, i. e., among this suite of objects there is also not a single one with the high abundance ratios we are talking about.

In closing we repeat our conclusion that metal imports in Luristan, zone I were less important than previously thought and that, in zone III and in Pish-i Kuh, they may have been quasi non-existent. These results are essentially based on the lead isotope data while the trace element concentrations do not allow us to distinguish between Luristan bronzes and such from Mesopotamia. Had we only measured the chemical composition we might have concluded, as did Fleming et al. (2005), that during the 4th and 3rd millennia BCE Luristan should have been well-embedded in the trading and exchange system of goods within the Near East with nothing that sets it apart from, say, Mesopotamia or Elam. Their suggestion, however, that in Luristan we see Afghan tin and copper from Oman appears to us not to follow immediately, not even from the chemical data.

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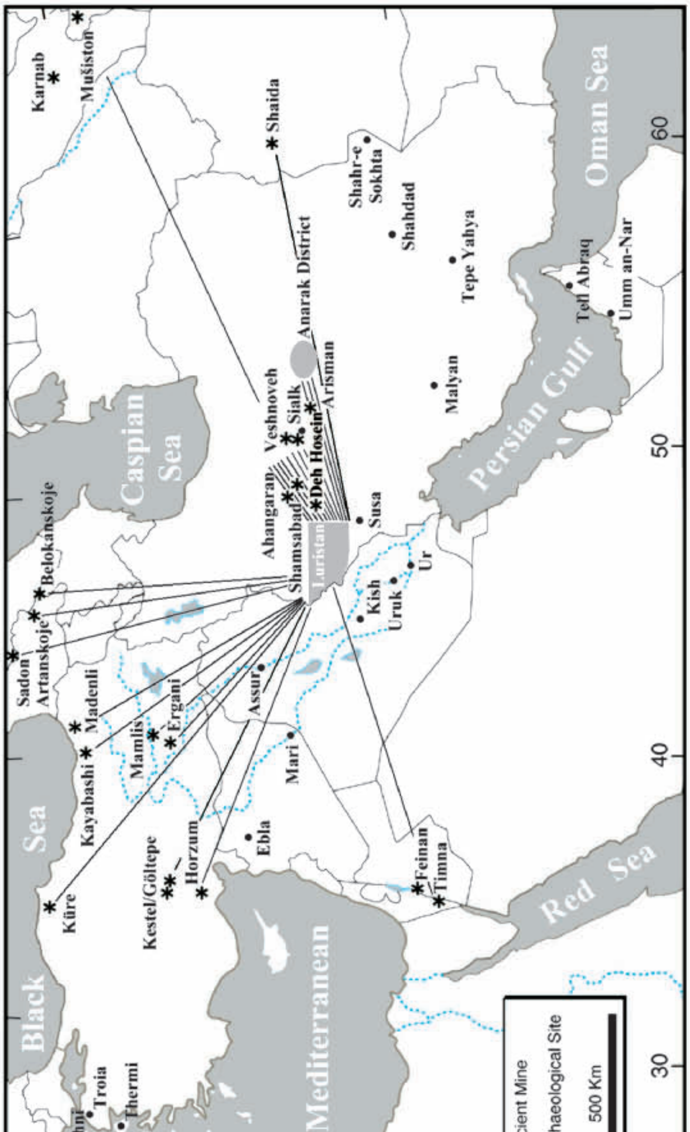

Fig. 13. Potential ore sources for the metal of copper-base artefacts from Luristan. Of the 69 objects analysed for the isotopic composition of their lead the largest fraction by far can be traced to deposits in the eastern part of the Central Zagros Mountains and on the Iranian Plateau. Prominent are ores from the polymetallic Cu/Sn deposit of Deh Hosein while the Anarak district plays only a minor role. Note, that the assignments are solely based on a comparison of the lead isotopy; additional chemical data make ore sources in Anatolia unlikely.

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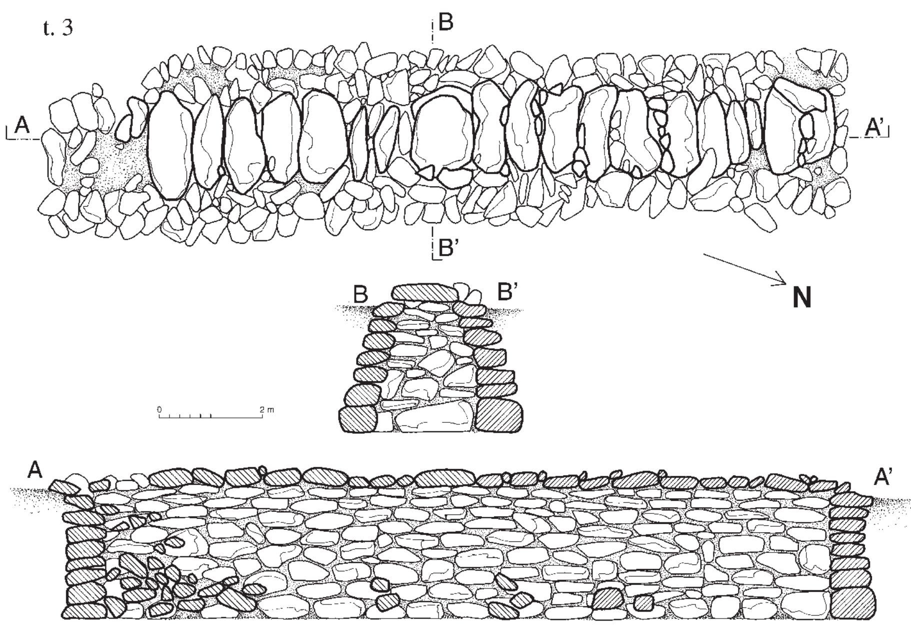
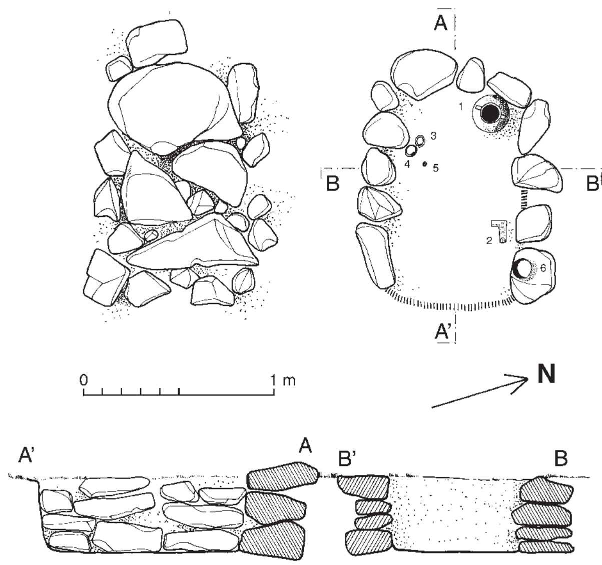
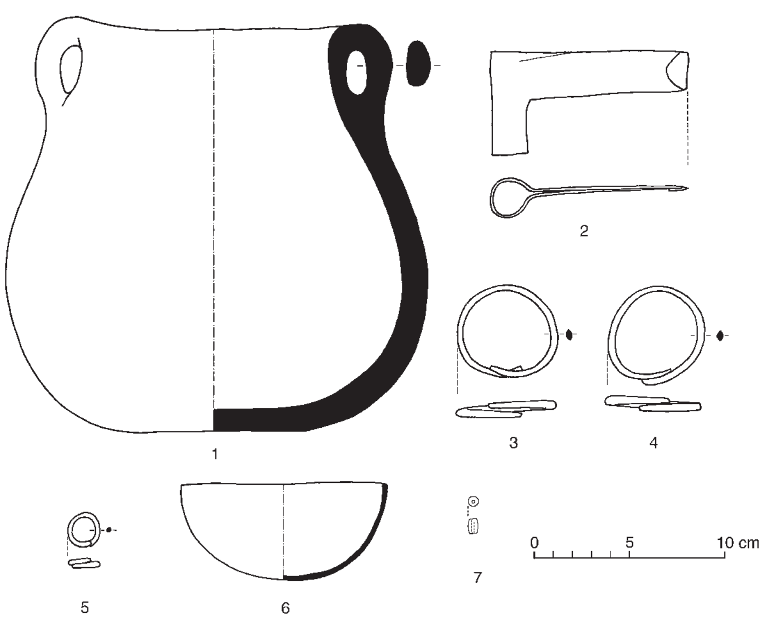


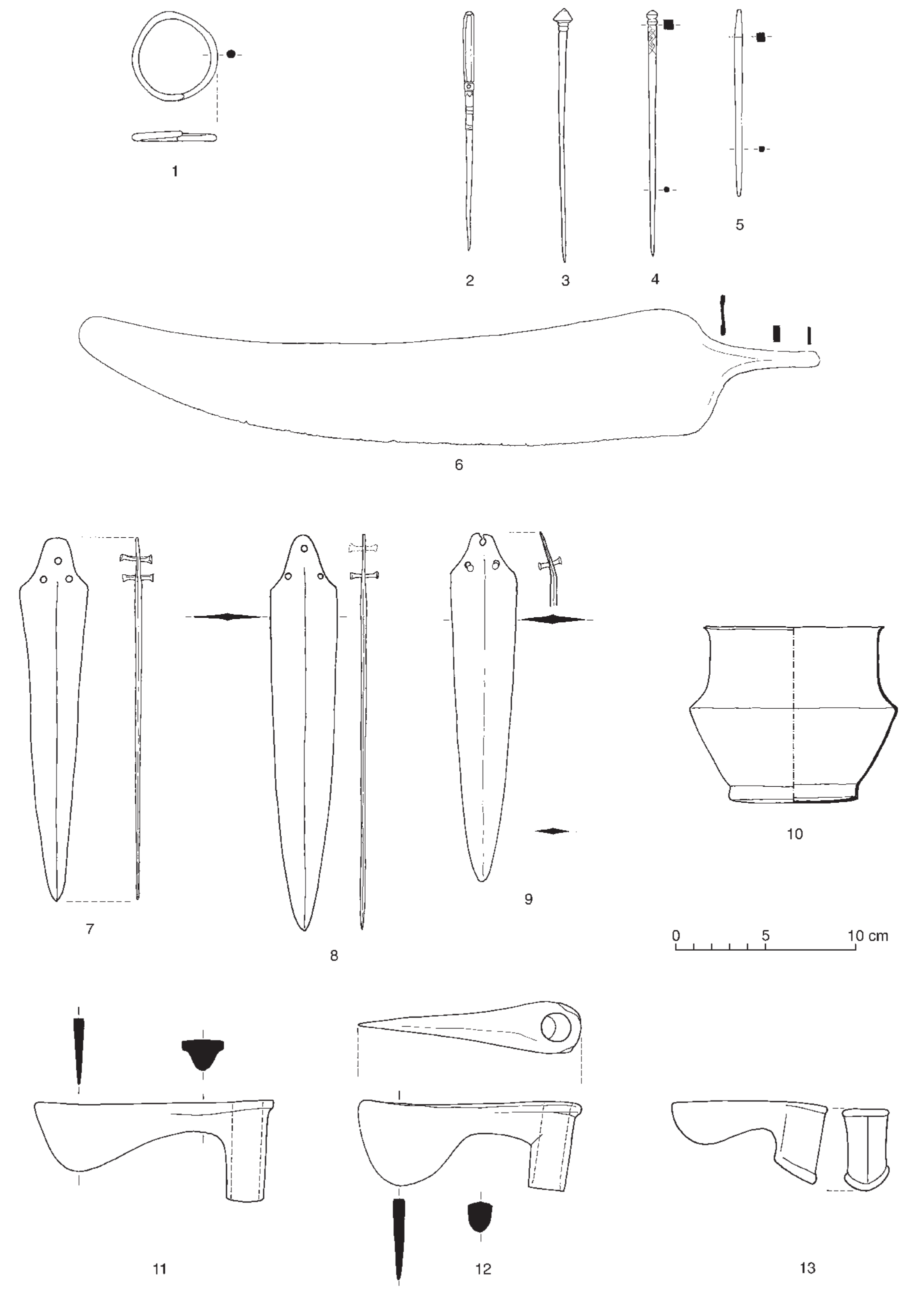
Pl. 1. Phase II corridor-shaped communal tombs in zone I of the Pusht-i Kuh, Luristan. Top: tombs at Bani Surmah. Bottom: Plan of tomb C3 at Kalleh Nisar (objects of tomb KN.C3 have been analysed, see BAMI-27 and 29). (Photographs and drawings by E. Smekens)

t. 2



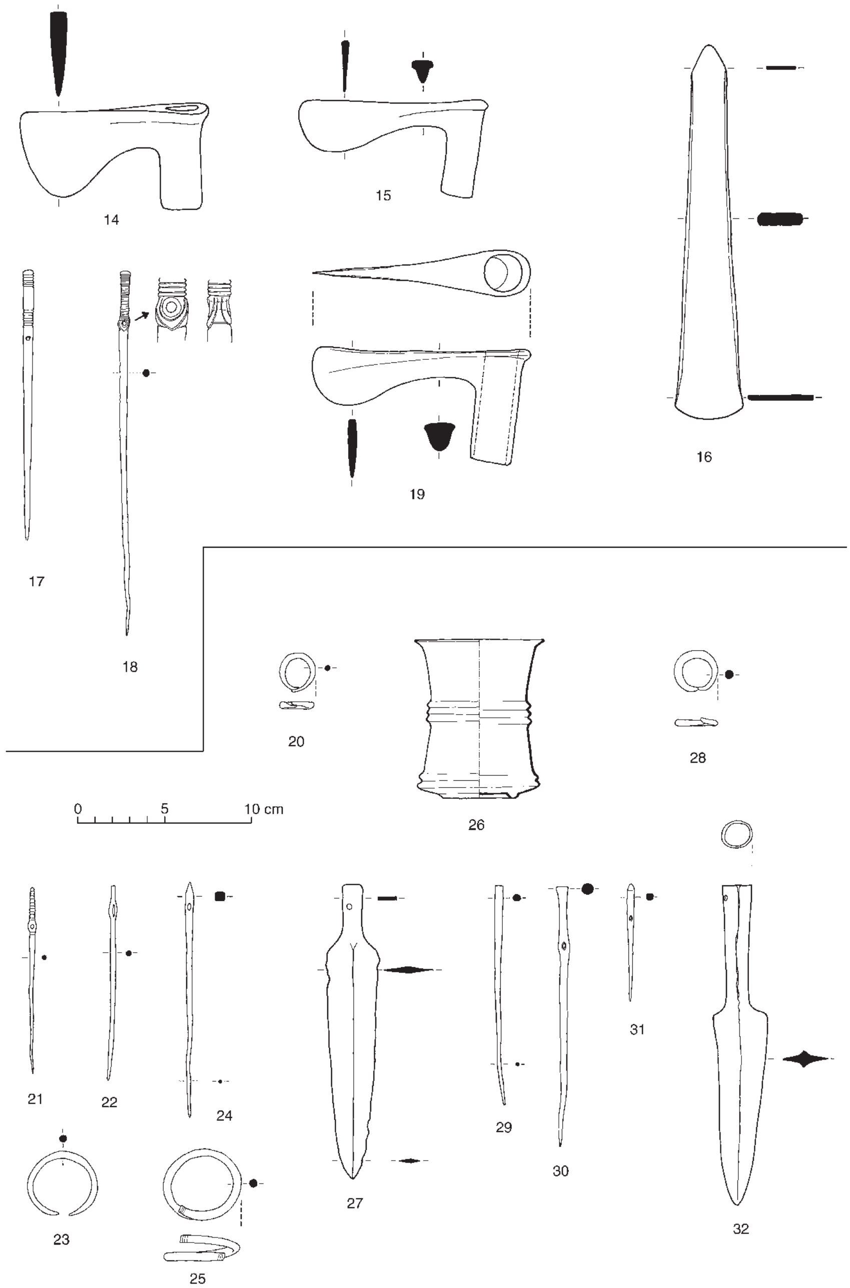


Pl. 2. The individual Phase IV tomb 2 at Kalleh Nisar AII (objects KN.AII.2-2 and 2-6 have been analysed, see BAMI-43 and 50). (Drawings by E. Smekens)

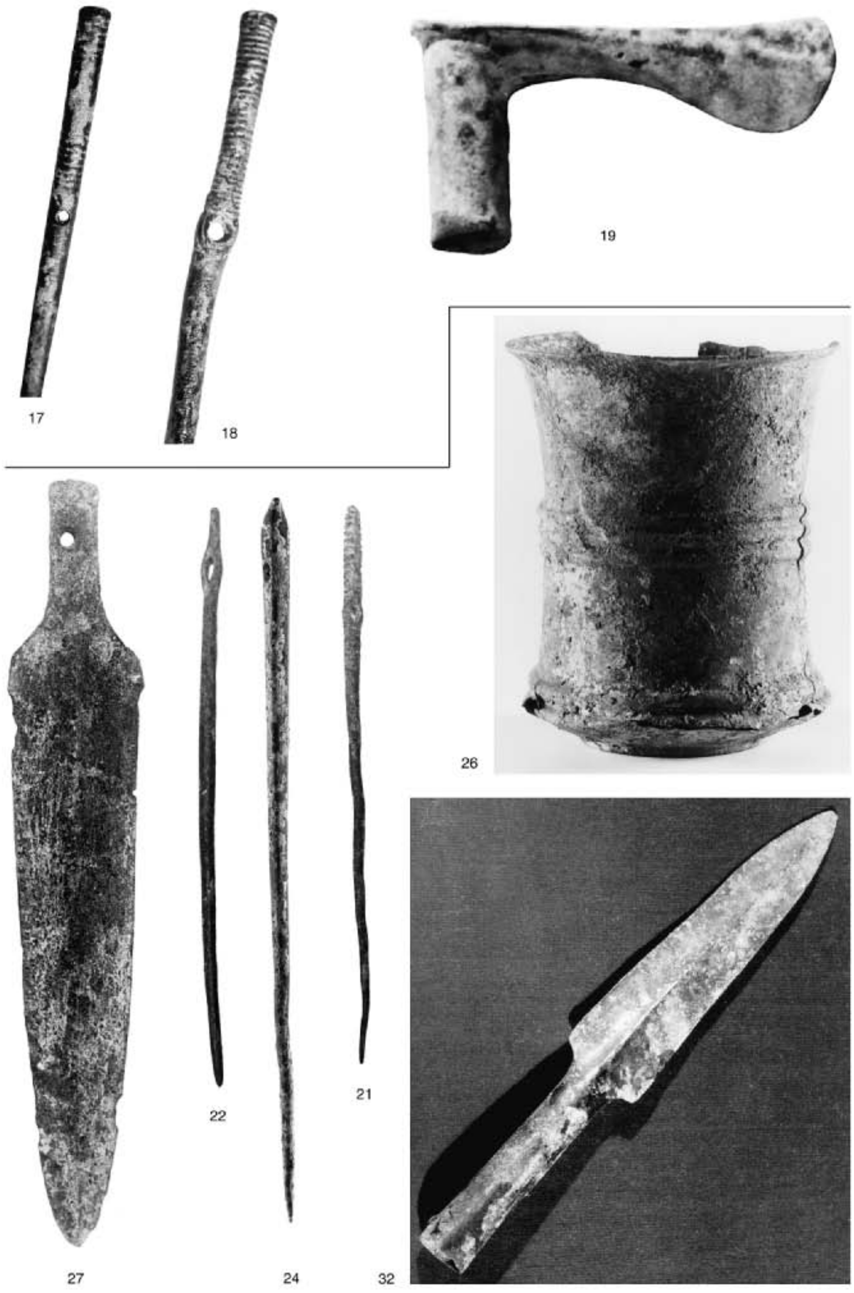


Pl. 3. Analysed metal objects from the Pusht-i Kuh excavations at Bani Surmah: BAMI-1 to 13. (Royal Museums of Art and History, Brussels-Collection Iran; drawings and plate by E. Smekens.)

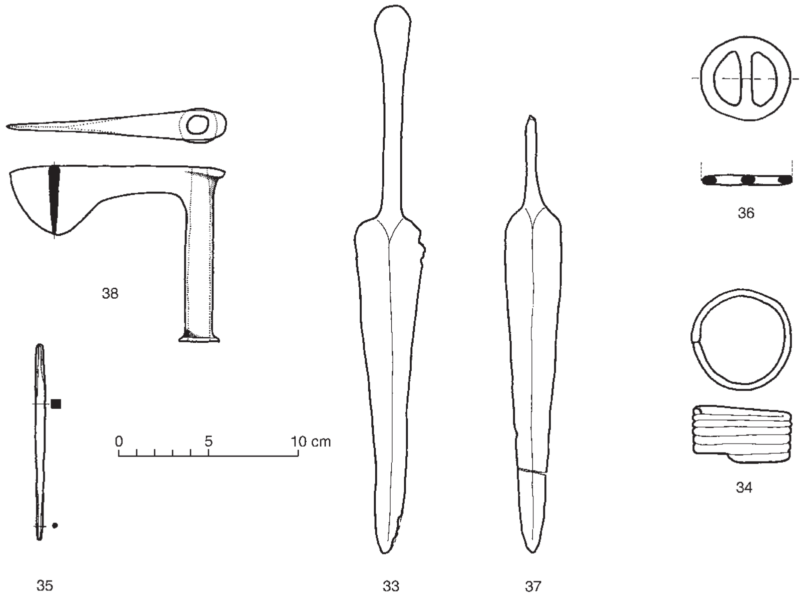
Pl. 4. Analysed metal objects from the Pusht-i Kuh excavations at Bani Surmah: BAMI-6, 8, 10, 11 and 13. (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)



Pl. 5. Analysed metal objects from the Pusht-i Kuh excavations at Bani Surmah (BAMI-14 to 19) and Kalleh Nisar (BAMI-20 to 32). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens)

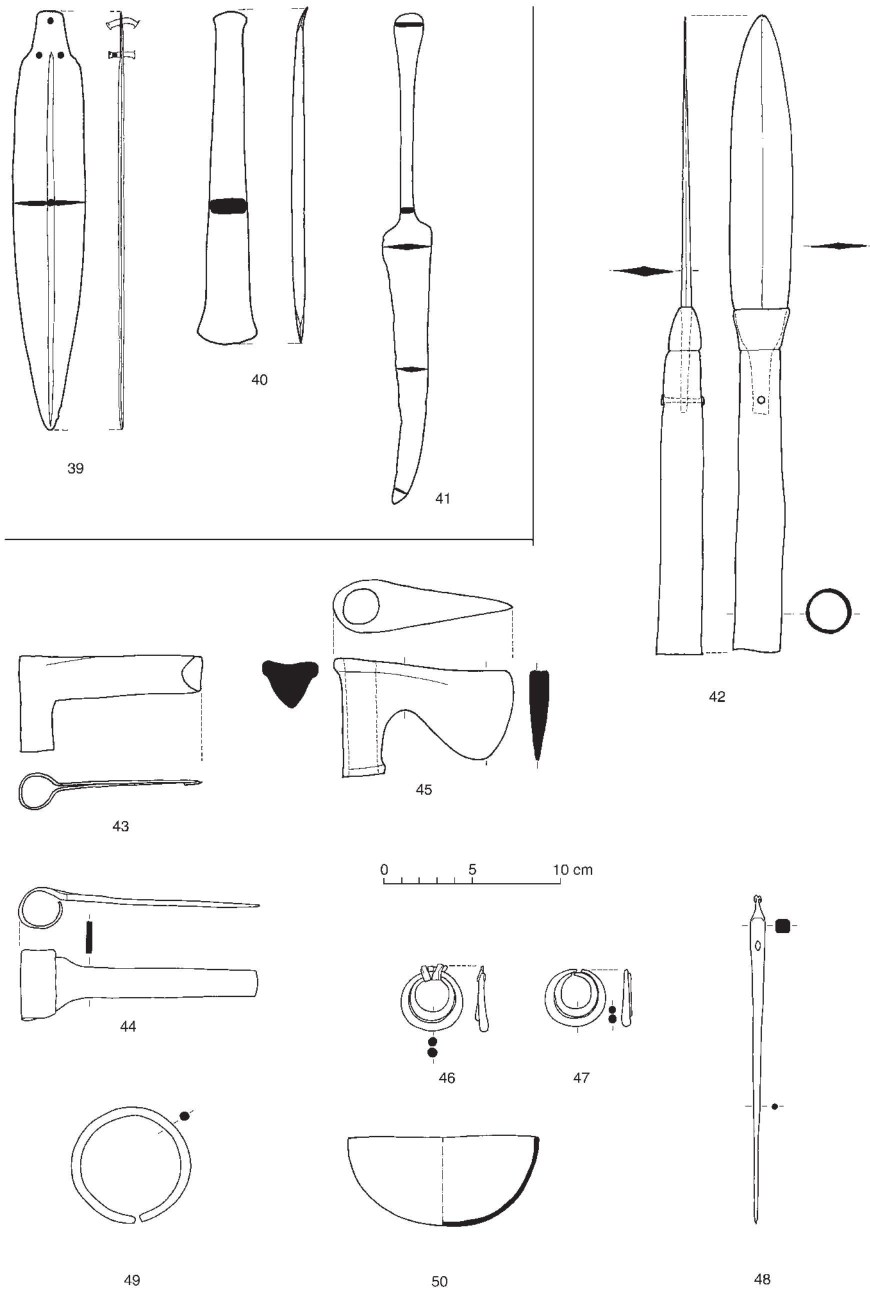


Pl. 6. Analysed metal objects from the Pusht-i Kuh excavations at Bani Surmah (BAMI-17 to 19) and Kalleh Nisar (BAMI-21, 22, 24, 26-27 and 32). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)



Pl. 7. Analysed metal objects from zone III tomb at Dar Tanha (BAMI-33 to 38) and view of the tomb with its gabled roof during the excavations. (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)

Pl. 8. Analysed metal objects from zone III tomb at Dar Tanha (BAMI-33 to 38). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)



Pl. 9. Analysed metal objects from the Pusht-i Kuh excavations at Mehr War Kabud (BAMI-39 to 41) and Kalleh Nisar A II (BAMI-42 to 50). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)

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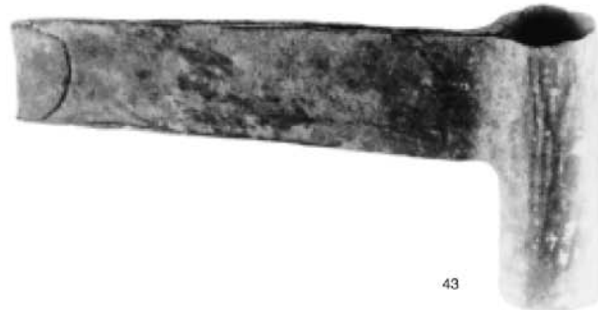

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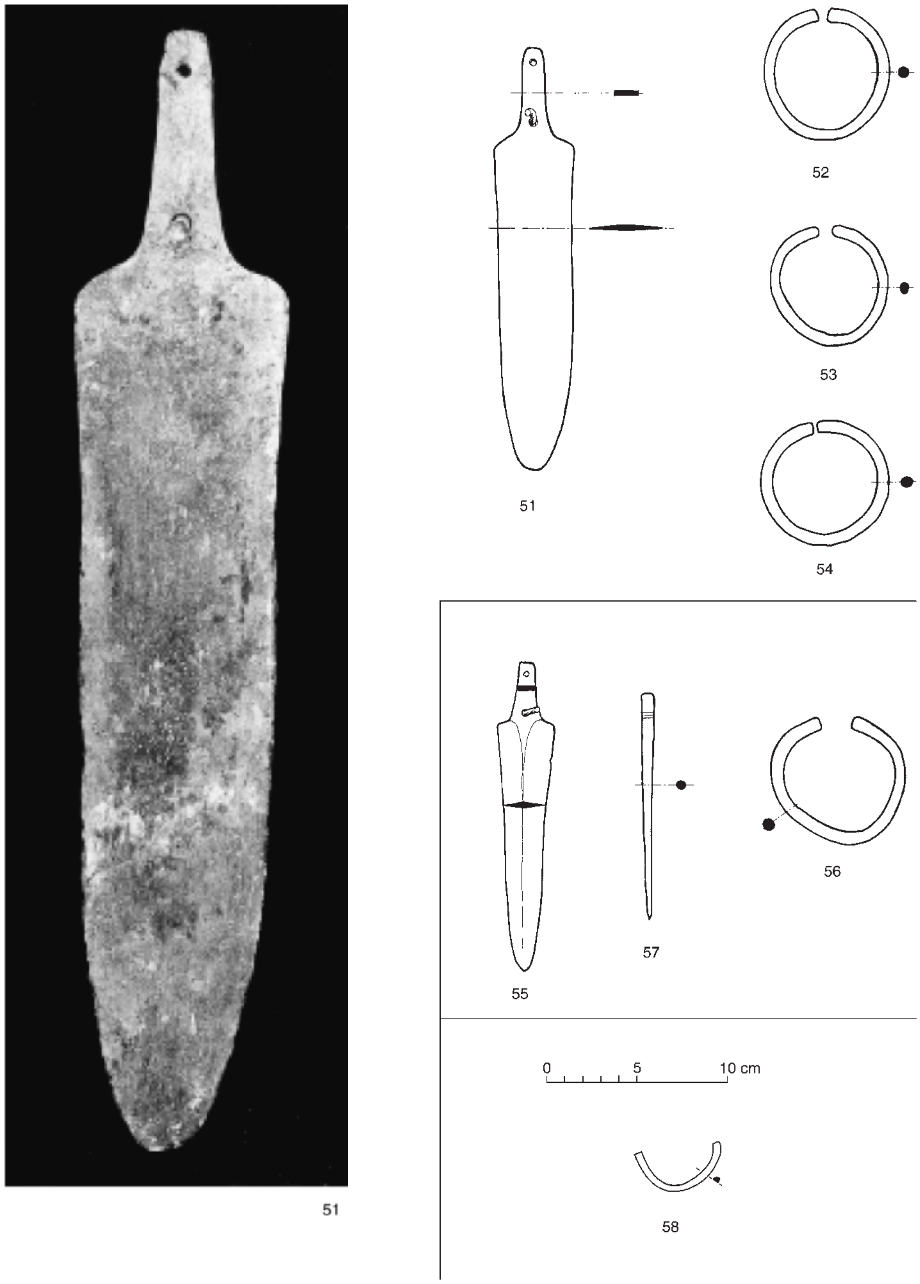
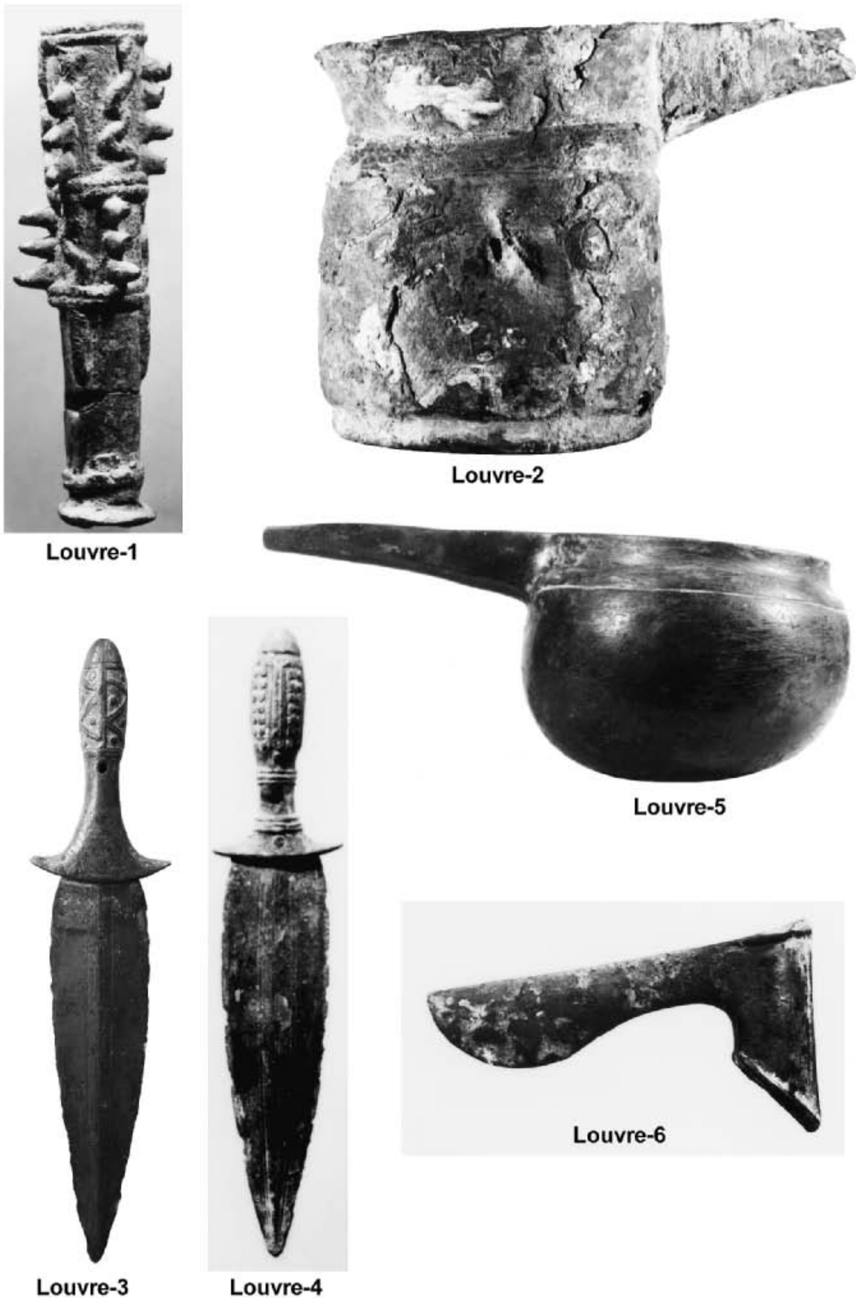
Pl. 10. Analysed metal objects from the Pusht-i Kuh excavations at Mehr War Kabud (BAMI-41) and Kalleh Nisar A II (BAMI-43, 44, 46-47 and 50). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)



Pl. 11. Analysed Phase IV metal objects from the Pusht-i Kuh excavations at Sardant (BAMI-51 to 54), Gululal-i Galbi (BAMI-55 to 57) and Darvand A (BAMI-58). (Royal Museums of Art and History, Brussels-Collection Iran; plate by E. Smekens.)



Pl. 12. Analysed metal objects from the Louvre collection (Louvre 1 to 6). (Photographs kindly supplied by the Réunion des Musées Nationaux © / nr. 3, ©Photo RMN - Les Frères Chuzeville)

Louvre-7

Louvre-8

Louvre-9

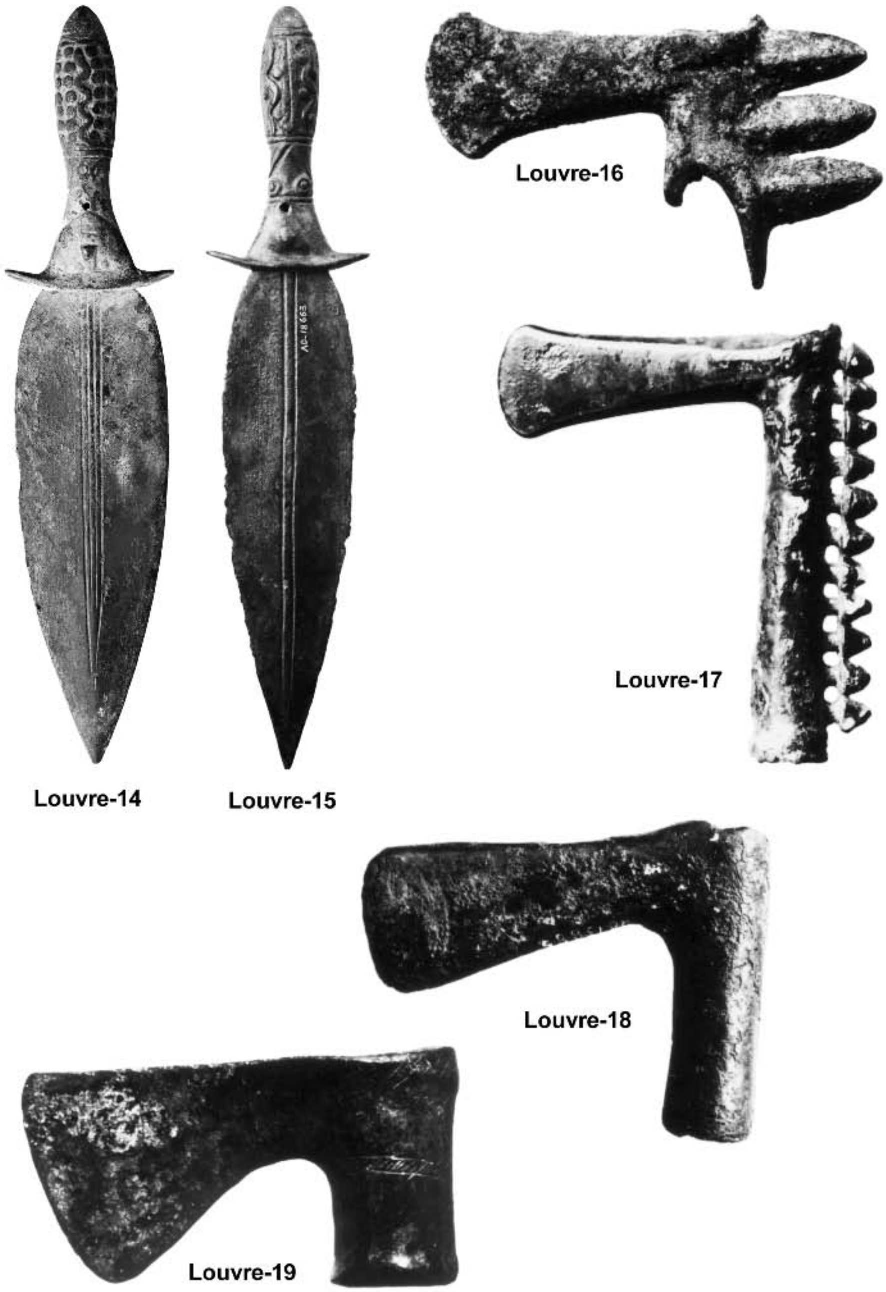
Louvre-10

Louvre-11

Louvre-12

Louvre-13

Pl. 13. Analysed metal objects from the Louvre collection (Louvre 7 to 13). (Photographs kindly supplied by the Réunion des Musées Nationaux © / nr. 13, ©Photo RMN - Les Frères Chuzeville)



Pl. 14. Analysed metal objects from the Louvre collection (Louvre 14 to 19).
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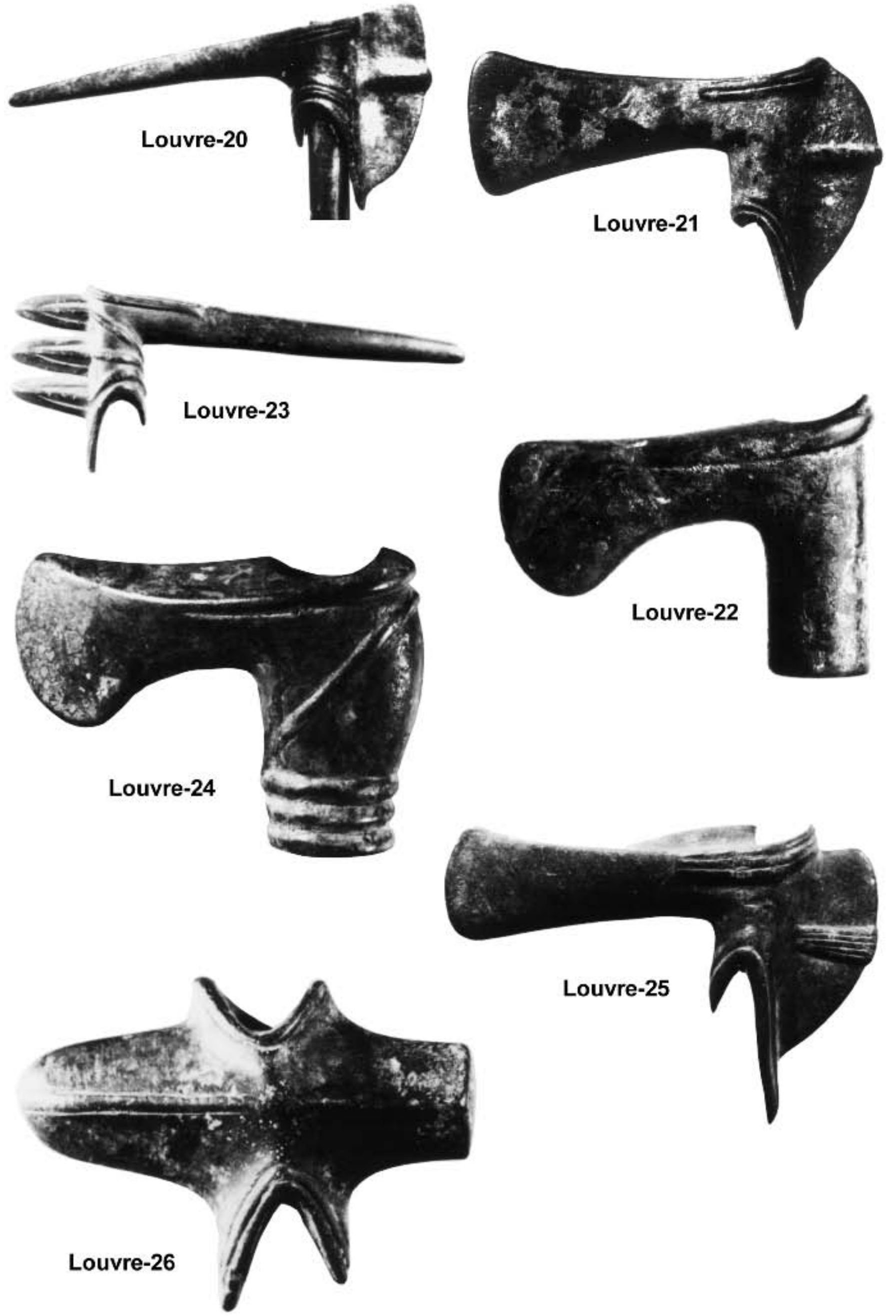

Pl. 15. Analysed metal objects from the Louvre collection (Louvre 20 to 26).
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Pl. 16. Analysed metal objects from the Louvre collection (Louvre 27 to 32).
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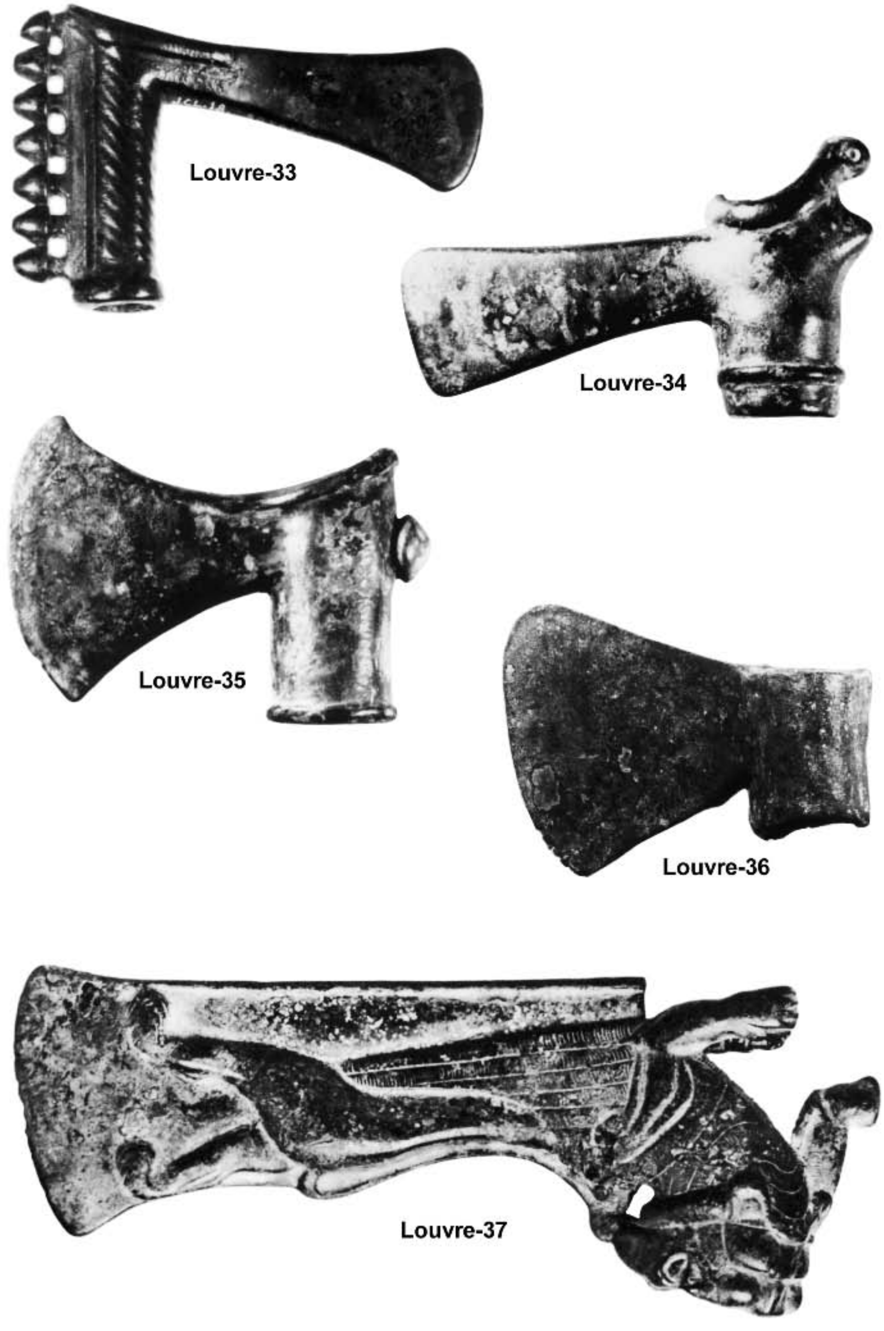

Pl. 17. Analysed metal objects from the Louvre collection (Louvre 33 to 37).
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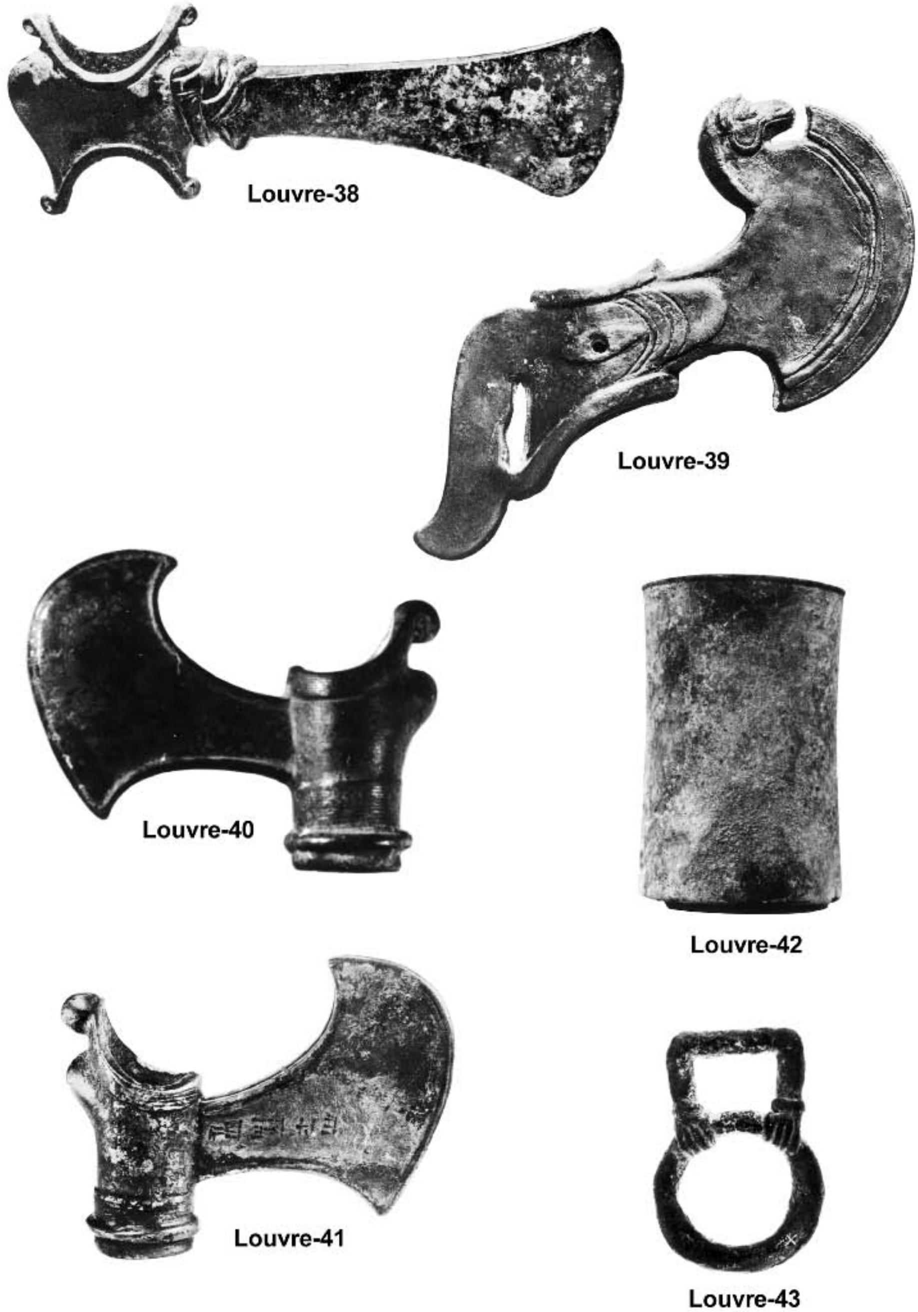

Pl. 18. Analysed metal objects from the Louvre collection (Louvre 38 to 43).
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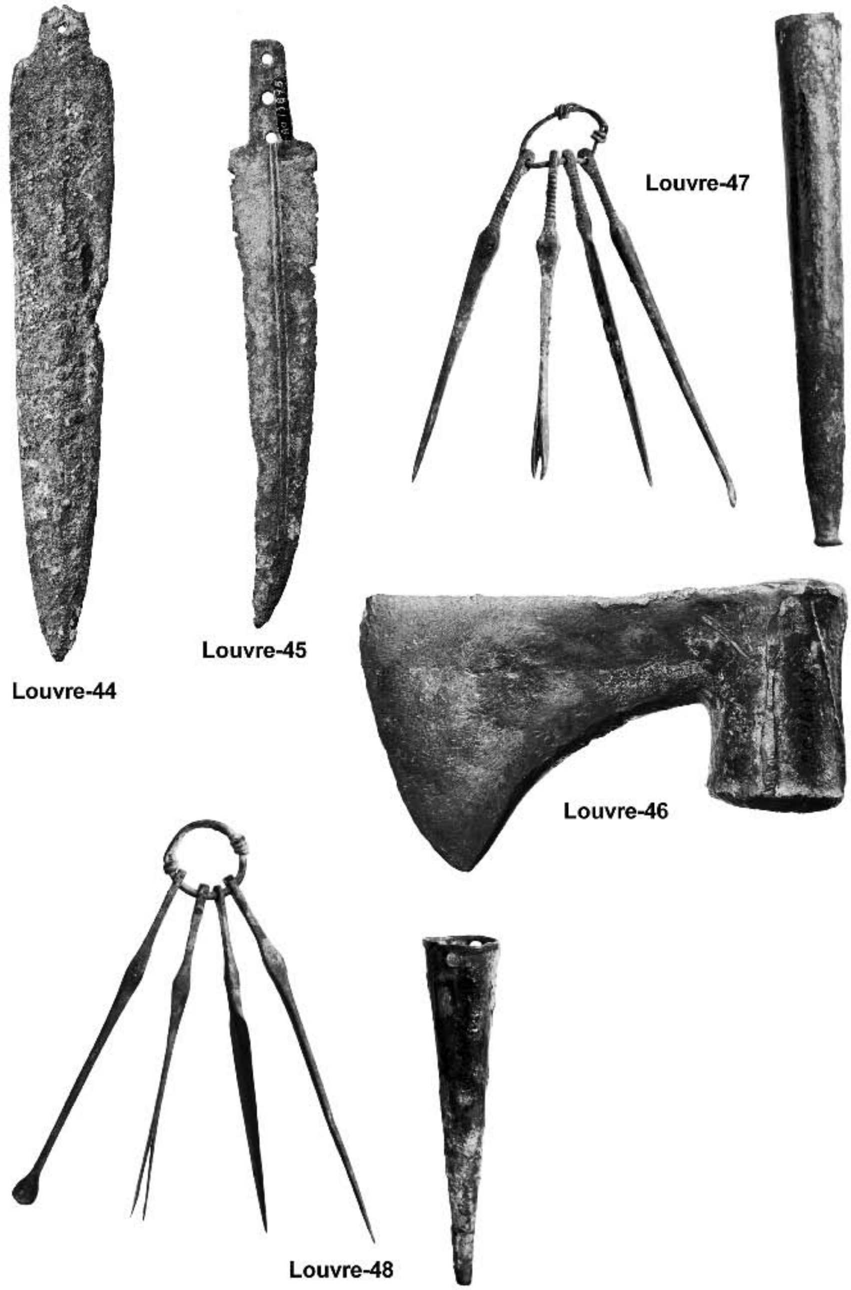

Pl. 19. Analysed metal objects from the Louvre collection (Louvre 44 to 48).
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